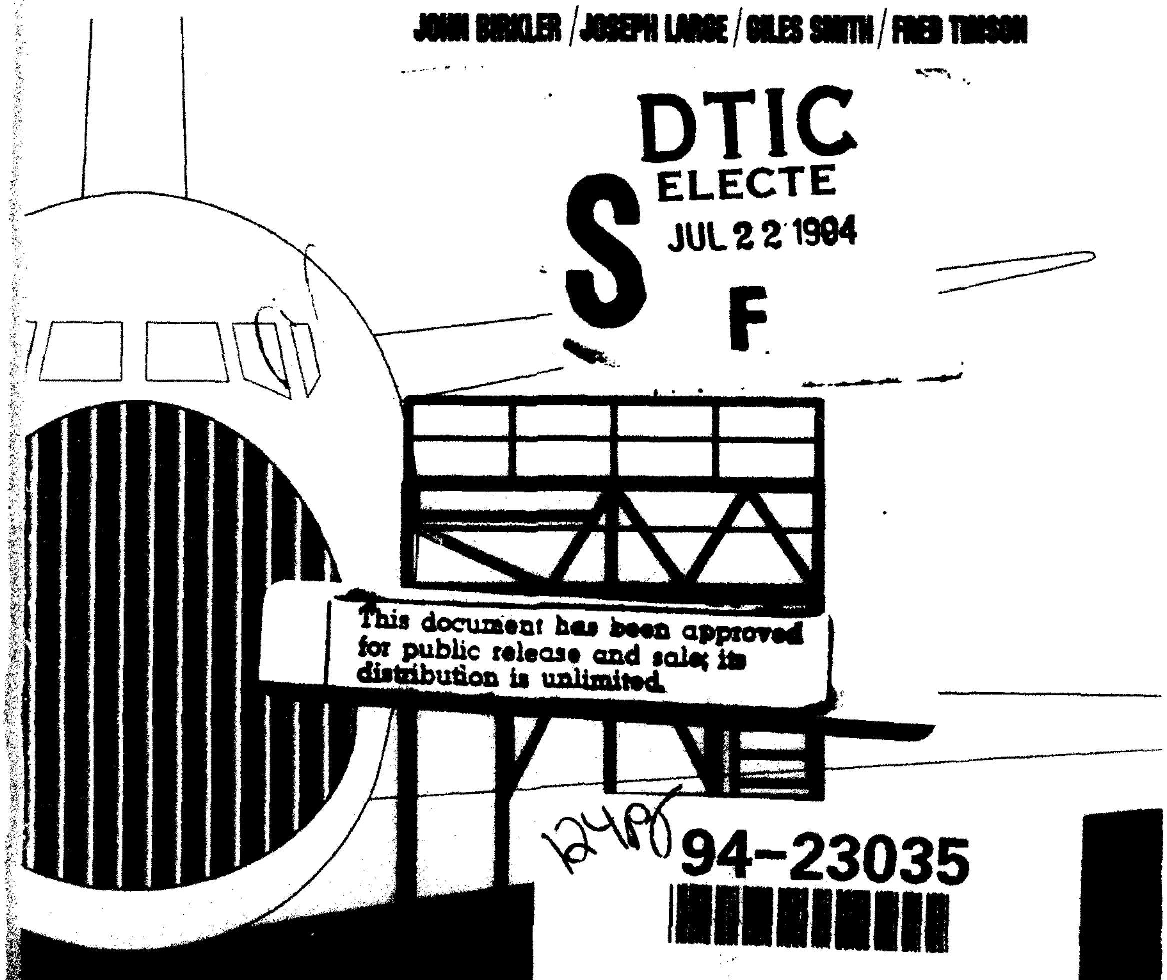
RECONSTITUTING A PRODUCTION CAPABILITY

PAST EXPERIENCE, RESTART CRITERIA, AND SUGGESTED POLICIES

JOHN BIRKLER / JOSEPH LARGE / GILES SMITH / FRED TIMSON



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RAND

PREFACE

This report provides an overview of a RAND research project entitled "Reconstituting a Production Capability." The research focused on understanding, identifying, and quantifying procurement practices and policies that would enable DoD to reconstitute the production capacity for critical weapon systems and to assess the attractiveness of the reconstitution option relative to other acquisition strategies.

This report should be of interest to policymakers, policy analysts, resource managers, and those persons responsible for and engaged in the process of acquiring weapon systems.

This project was sponsored by the Office of Acquisition Policy and Program Integration, Office of the Under Secretary of Defense for Acquisition. It was undertaken within the Acquisition and Support Policy Program of RAND's National Defense Research Institute, a federally funded research and development center sponsored by the Office of the Secretary of Defense and Joint Staff.

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SUMMARY

With the transition to lower U.S. military force levels, near-term reductions in defense procurement seem inevitable. Budget pressures will dictate not only that smaller quantities of individual weapon systems be acquired but also that many long-enduring production lines be shut down. In addition, production lines of new weapon systems may well be dismantled soon after the initial production runs are complete.

At the same time, the United States must maintain a capability to respond to regional conflicts that threaten U.S. interests and to reconstitute its forces in the event of extended conflicts. Indeed, reconstitution is one of the four foundations of the new national military strategy enunciated by President George Bush in 1990.

In this report, we examine one promising reconstitution option: activating the industrial base to produce major weapon systems whose production lines have been shut down. This report examines the following major production-restart issues: cost and schedule relative to those of new programs, measures to ameliorate the problems of restart, criteria for selecting restart candidates, and alternative reconstitution strategies. The specific questions we set out to answer and the conclusions we reached are as follows.

WHAT DOES EXPERIENCE SHOW REGARDING THE SCHEDULE AND COST OF RESTART COMPARED WITH THOSE OF ORIGINAL PRODUCTION?

Current acquisition practices include a demonstration and validation phase, prototypes, and extensive risk-reduction activities, which cumulatively could stretch an "all-new" acquisition program out to ten years. We obtained data for 11 aircraft programs that were shut down and restarted or for which restart was seriously considered. We found that, beginning from the time the production contract is signed, it takes about one or two years less to produce the first unit for restarted production than for original production. This is a very conservative estimate of restart's schedule advantage, because, in a restart program, an entire support network—maintenance personnel, spares, manuals, special test equipment, etc.—is already in place. That network, together with previous experience in testing the system, should result in a savings of many years in achieving a force with operational readiness equal to that resulting from original production. Furthermore, restarting production of an item that is already in service presents a very low risk compared with developing and producing a new system.

In addition to its schedule advantage, restart has a cost advantage. On average, the initial restart unit requires only about 10 percent of the one-time (nonrecurring) labor input that the initial original-production unit needs. As for recurring costs, the first restart-production units require approximately half as much production and quality-assurance labor and only about 40 percent of the tooling labor and 20 percent of the engineering labor as the original first unit. In virtually all the programs we examined, however, restart production experienced a learning curve with a shallower slope than that of original production. That is, the reduction in labor input with each succeeding unit was less on a percentage basis for restart than for original production.

The data and analyses presented in this study clearly and consistently indicate that restarting aircraft programs that have previously achieved full-production capability and then been shut down should result in follow-on programs that require less time from program start to first delivery and should be significantly less expensive than the original program.

WHAT ACTIONS SHOULD BE TAKEN AT SHUTDOWN TO FACILITATE EFFICIENT RESTART?

Ensuring that restart's time and schedule advantages are realized may require that certain actions be taken when a production line is shut down that would not be taken otherwise. Interviews with air-frame, missile, and other major weapon-system contractors reveal general agreement on the elements of "smart shutdown." Certain physical assets, data, and know-how were identified and agreed to as being essential to a smooth restart by virtually all contractors interviewed.

The investment required to preserve the essential items is quite modest compared with the original acquisition cost, and a very modest dollar investment at shutdown could save hundreds of millions of dollars in the event restart is required. Contractors, however, have little incentive to incur even modest costs for storing important items, some of which may be bulky and useless until restart gets under way, if it ever does.

To ensure smart shutdown, DoD should fund contractor efforts to preserve those documents, tools, etc., that are needed to restart production. As part of this process, videotapes and photographs of fabrication and assembly activities should be made, not only to record how the system was produced but to serve as training aids for follow-on workers. Interviews with key shop and technical personnel should be part of such documentation. The preservation activity need not be expensive; indeed, it can cost less than routine disposal of tools in accordance with government regulations.

The key to the effectiveness of this technique is the thoroughness with which shutdown activities render paper and hardware ready for reuse by an entirely new set of people with minimal confusion at the time of restart years later.

HOW SHOULD RESTART CANDIDATES BE SELECTED?

In an era of declining resources, DoD should not spend even modest extra sums in shutting down production for systems unlikely to be restarted. To aid DoD in avoiding such expenditures, we sought answers to the following questions: How should DoD go about identifying possible restart candidates? Would most systems have to be put through restart-facilitating shutdown? Can useful generalizations be made about restart candidates?

We identified several criteria that weapon systems currently in procurement should satisfy if they are to be considered candidates for restart:

- Is the production run complete or nearing its end?
- Is the system likely to suffer significant losses or consumption during future conflict? Frontline systems such as fighter aircraft are more likely to require force reconstitution.
- Is it difficult to identify deployed or programmed systems that could substitute operationally?
- Is it practical to restart production? For example, could units be available soon enough? Would they have sufficient operational life prior to obsolescence?

For illustrative purposes, we applied the first three criteria to 115 weapon systems across all military services. Only 30 percent were identified as potential candidates for restart. Our intent here was not to recommend specific restart candidates; the list that DoD eventually develops with its own expertise would probably be different from ours, but we doubt it would be much longer. Application of the fourth criterion—too situation-specific for us to apply—would reduce the list further. The decision to restart would occur at some time in the future and would depend on projected military requirements at the time. Thus, the modest costs of efficient shutdown need only be incurred for a minority of systems.

Such systems are likely to be those requiring relatively large investments in production resources (plant, tooling, etc.) and involving long industrial lead times (several years from order placement to delivery). This class of systems poses the most difficult planning challenges in reaching a compromise between near-term economy and long-term capability to meet force needs that are not now programmed.

WHAT ALTERNATIVES TO PRODUCTION RESTART MIGHT BE USEFUL?

Production restart is only one of several possible strategies for supporting reconstitution of forces. Two additional options that might be applied to either current or future weapon systems are:

- Maintaining production at a very low rate, possibly deferring satisfaction of immediate needs in return for sustaining an active production line over a longer period of time
- Producing at a high (efficient) rate beyond immediate needs and storing the excess for use in future contingencies.

Each strategy involves a different balance between near-term costs (which might be one-time or recurring) and the time and cost required for producing additional quantities of an item in the future. Each should be the subject of additional research, including examination of cost and schedule consequences across weapon system types and a range of scenarios.

CAVEATS

In interpreting and acting on our results, three important caveats must be kept in mind.

First, *our database is limited to a few types of systems.* Only a very limited number of programs have undergone a restart, and in those only very limited steps were taken at the time of shutdown to facilitate restart.

Second, *we have no information on the practicality of restarting production of an item when the original developer and producer are no longer available.* Anecdotal evidence suggests that restart in that situation would still be possible, but time, cost, and risk parameters remain outside our experience and are speculative.

Third, *our experience is limited to situations in which an adequate body of trained, or readily trainable, manufacturing workers can be hired.* If a whole industry, such as aircraft or ship fabrication and assembly, falls into serious decline and a generation of skilled workers is allowed to disperse, restarting a production line might be less practical than recent experience indicates. Of course, under such circumstances, starting a new program may be even more daunting.

ACKNOWLEDGMENTS

This work could not have been undertaken without the special relationship that exists between the Office of the Secretary of Defense (OSD) and RAND under the National Defense Research Institute (NDRI). For that relationship we are grateful. Many individuals in OSD and at RAND deserve credit for the work discussed in this report. Their names and contributions would fill several pages. If we were to single out a senior person in OSD and another at RAND who participated in and supported this work in extraordinary ways, we would mention Gene Porter, Principal Deputy Director, Acquisition Policy and Program Integration, and Michael Rich, Director, NDRI. We would also like to acknowledge CDRs Christopher Larsen and Joseph Littleton, who, while serving as Navy Executive Fellows at RAND, made significant contributions to the methodology described in Chapter Four.

We also want to thank the following contractors who contributed to this research project either by providing historical or proposal data, being interviewed regarding past experience or planning, or participating in a workshop held at RAND: Boeing, Lockheed, Rockwell, Vought, Kaman, Douglas, and Hughes. Their participation made possible the analyses described here.

ACRONYMS AND ABBREVIATIONS

ACM	Advanced cruise missile
ADATS	Air Defense Anti-Tank System
AFATDS	Advanced Field Artillery Tactical Data Systems
AGM	Air-to-surface missile
AHIP	Army Helicopter Improvement Program
AIM	Air-to-air missile
ALCM	Air-launched cruise missile
AMRAAM	Advanced medium-range air-to-air missile
AMS-H	Advanced Missile System—Heavy
AN/BSY	Submarine Combat System
AN/SQQ	Surface Ship Sonar System
AN/UYS	Signal processor
AOE	Fast combat support ship
ASAS	All-Source Analysis System
ASM	Armored Systems Modernization
ASUW	Anti-surface warfare
ASW	Anti-submarine warfare
ATACMS	Army Tactical Missile System
ATARS	Advanced Tactical Air Reconnaissance System
ATCCS	Army Tactical Command and Control System
BPDMS	Basic Point Defense Missile System
CBU	Cluster bomb unit
CG	Guided missile cruiser
CH	Cargo helicopter
CIWS	Close-in weapon system
CLF	Combat Logistics Force
CPFF	Cost plus fixed fee
CPIF	Cost plus incentive fee

CSRL	Common strategic rotary launcher
CSSCS	Combat Service Support Control System
CVN	Nuclear-powered aircraft carrier
DAR	Defense Acquisition Regulation
DCAA	Defense Contracts Audit Agency
DDG	Guided-missile destroyer
DMSP	Defense Meteorological Satellite Program
DoD	Department of Defense
DSCS	Defense Satellite Communications System
DSP	Defense Support Program
EMD	Engineering and Manufacturing Development
EW	Electronic warfare
FAADS	Forward-Area Air Defense System
FAR	Federal Acquisition Regulation
FFG	Guided-missile frigate
FFP	Firm fixed price
FHTV	Family of heavy tactical vehicles
FMS	Foreign Military Sales
FMTV	Family of medium tactical vehicles
FPI	Fixed-price, incentive
FVS	Fighting Vehicle System
GD	General Dynamics
GLCM	Ground-launched cruise missile
GPS	Global Positioning System
IOC	Initial operational capability
IUS	Intermediate Upper Stage
JSTARS	Joint Surveillance Target Attack Radar System
JTIDS	Joint Tactical Information Distribution System
LANTIRN	Low-Altitude Navigation and Targeting Infrared System for Night
LCAC	Air cushion landing craft
LHD	Amphibious assault ship
LIC	Low-intensity conflict
LRU	Line replaceable unit
LSD	Dock landing ship
MCM	Mine countermeasure ship
MCS	Maneuver Control System
MHC	Coastal mine hunter ship
MLRS	Multiple-Launch Rocket System
MRF	Multi-Role Fighter

MSE	Mobile Subscriber Equipment
NC	Numerical Control
OSD	Office of the Secretary of Defense
PI	Production Illustration
PIR	Production Inspection Record
PPPI	Pre-Planned Product Improvement
RGM	Ship-launched surface attack missile
RIM	Ship-launched air-intercept missile
RMP	Reprogrammable microprocessor
SADARM	Sense-and-Destroy, Anti-Armor Munition
SAR	Selected Acquisition Report
SINCGARS	Single-Channel Ground and Airborne Radio System
SLAM	Stand-off land attack missile
SOF	Special Operations Forces
SSN	Nuclear-powered attack submarine
T-AGOS	Ocean surveillance ship
T-AO	Fleet oiler
UGM	Submarine-launched surface attack missile
USMC	U.S. Marine Corps

Chapter One

INTRODUCTION

BACKGROUND

The fundamental objective of America's armed forces is to deter aggression and, should deterrence fail, to defend the nation's vital interests against a potential foe. To accomplish this objective in the current world environment, a new national defense strategy has been articulated.[1] It is a strategy built upon four pillars: strategic deterrence and defense, forward presence, crisis response, and reconstitution.[2] This report examines reconstitution of weapon system production capability. It focuses on one promising means to achieve that reconstitution—activating the industrial base to produce major weapon systems whose production lines have been shut down.

In the world now emerging, few nations will possess forces that pose a challenge to U.S. national interests significant enough to require reconstituting the massive U.S. forces of the Cold War era. Over time, however, coalitions could form or foreign forces might be created, mobilized, or redeployed in ways that could pose clear threats to the United States or its allies. The country may also face the need to rebuild U.S. inventories after they have suffered serious attrition in some limited engagement. In a future conflict similar to the Gulf War, for example, 100 to 200 aircraft might conceivably be lost.

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[1]President Bush's speech in Aspen, Colorado, on August 2, 1990.

[2]U.S. Joint Chiefs of Staff, *National Military Strategy, 1992*, Washington, D.C., January 1992.

Given that the United States may have to reconstitute forces in response to external threats or circumstances, how should it be done? With the transition to lower U.S. military force levels, near-term reductions in defense procurement are inevitable. Budget pressures will dictate that smaller quantities of individual weapon systems be acquired and that many long-existing production lines be shut down. In addition, the production lines of new weapon systems may well be dismantled soon after production runs are complete. These possibilities raise questions about means of rebuilding or replacing U.S. forces.

One approach would be to restart a production line that has been shut down for perhaps several years, providing that the resulting military capability meets the need. Restart offers two significant possible advantages over new system acquisition:

- It should be faster and less expensive to restart a production line than to develop and put into production a new system.
- It should be easier to integrate into the existing force additional quantities of a system that is already operational.

OBJECTIVES AND APPROACH

The research presented in this report focuses on understanding, identifying, and quantifying procurement practices and policies that would enable DoD (1) to assess the attractiveness of production restart relative to other reconstitution strategies, and (2) to facilitate restart should it be judged desirable by DoD. Primary attention is devoted to weapon systems that require rather large investments in production resources (plant, tooling, etc.) and that involve long industrial lead times (several years from order placement to delivery). This class of systems poses the most difficult choices in reaching a compromise between near-term economy and a longer-term capability to rebuild or expand forces in a way that cannot be anticipated. Specifically, this research addresses four questions:

What does experience show regarding the schedule and cost of restart compared with those of original production? A limited number of weapon system programs have been restarted and provide some evidence of the savings achievable in time and money and some lessons that can be applied to the future. We examined several programs to understand the lead times needed to restart production, the nonrecurring and recurring cost implications of doing so, and the effect of acquisition practices and policies on the ease and speed of reopening a production line. (See Chapter Two.)

What actions should be taken at shutdown to facilitate efficient restart? To produce a checklist of measures that might be used to prepare for future production-line reconstitution, we sought answers to the following questions: What actions might save or avoid substantial future restart cost? Should a small cadre of contractor personnel be maintained? Which types of technical data and tooling need to be preserved and stored? Should an inventory of critical parts be bought prior to the dissolution of the subcontractor network? What should go into a restart plan? (See Chapter Three.)

How should restart candidates be selected? We first develop a set of criteria regarding the kinds of systems for which reconstitution might be reasonable under current procurement policy. Such criteria would include current acquisition status, likelihood of future need, availability of acceptable substitutes, quantity of units needed, system obsolescence, availability of original production facilities, etc. Then we apply the criteria to a representative set of weapon systems. (See Chapter Four.)

What alternatives to production restart might be useful? Managers will be confronted by a number of possible acquisition strategies. There is a trade-off, for example, between maintaining a very low production rate for the entire system or certain of its components and the alternative of completely shutting down, then restarting production. In Chapter Five, we identify a range of possible reconstitution strategies and policies and discuss them in the light of the production-restart problem.

In Chapter Six we summarize the findings.

Photograph courtesy of Lockheed Aeronautical Systems Company.

U.S. Air Force C5-B Cargo Aircraft Under Construction in a Production-Restart Program at Lockheed's Marietta, Georgia, Facility

Chapter Two

PRODUCTION-RESTART EXPERIENCE

In the course of this research, the only production-restart experience we found for weapon systems that require rather large investments in production resources (plant, tooling, etc.) and that involve long industrial lead times (several years from order placement to delivery) was for aircraft, helicopter, and missile systems.[1] Thus, we draw on and discuss production-restart experience in the context of those systems.

Although experience with aircraft-production restart is not widespread, all U.S. military services have had occasion to reopen production lines when circumstances indicated that doing so was the most practical means to obtain additional systems. Aircraft manufacturers have also either used, or seriously considered, restarting production for commercial aircraft, e.g., the Lockheed Jetstar and Boeing 707. The issue, then, is not the viability or practicality of this concept; it is whether production restart is the best choice given the requirements of a particular program. We discuss some of the factors bearing on that choice in this chapter. In particular, we are interested in answers to the following two questions:

1. What is the general magnitude of restart production cost and schedule compared with that of the original programs?

[1] Our original intent was to gather data across a range of major system types. However, experience and available data existed primarily for aircraft systems. Small munitions production lines are routinely shut down and reopened. See Appendix A for lessons learned from those experiences. Naval ships are a special case; see Appendix B.

2. What factors, e.g., length of production gap, previous quantity produced, etc., have the most effect on restart costs?

EVIDENCE FROM EARLIER MODELS

Production breaks are not new, and they are not confined to the aerospace industry. They are common in companies manufacturing a variety of products, and their effect has been the subject of a number of studies. Most early studies were limited to their effect on direct manufacturing hours and to interruptions of a few months. Without exception, such studies were based on learning-curve theory, i.e., that the labor content in a product decreases by some constant percentage each time the production quantity doubles.

Some of the earlier models consider production labor only; none includes all the functional cost elements, i.e., engineering, tooling, quality assurance, etc.; and, all ignore nonrecurring costs. Also, most models are based on factory experience with components, line replaceable units (LRUs), or small systems for which total production hours are measured in the thousands or tens of thousands. Major systems of the type considered for restart generally involve millions of factory hours. There is no fundamental reason, however, why the structure of some of the models would not be useful for estimating the restart costs of major systems.

Stemming from a variety of sources, the models share many common assumptions. All presume that a production break will cause labor cost or hours to regress to some earlier point on the learning curve and that the slope of the curve will be unchanged by the break. If, for example, a learning-curve slope of 85 percent was experienced prior to a production break and loss of learning causes a regression back to unit 5, the production-restart curve will begin at the cost of unit 6 on an 85-percent curve.

All models stipulate that loss of learning increases over time; the more detailed models attribute the loss primarily to changes in both factory and supervisory labor. The models do not agree on the rate at which loss occurs, nor that the rate of loss is linear. Loss may be more pronounced in the first few months, then taper off, but length of break is always a factor.[2] Most models assume that the unit-1 cost in a production-restart program will never be as great as the original unit-1 cost, and that even 85 percent of original unit 1 would be an extreme case. Generally, the loss would be less.

Three models—Anderlohr,[3] GAPMODEL,[4] and Gilbride[5]—require judgments about five elements of production: production labor, supervisory labor, planning, methods, and tooling. The user must estimate the importance of each element in the program being considered and the residual contribution of each at the end of the production break. We recommend that estimators interested in working at that level of detail obtain copies of GAPMODEL and determine whether the model is suitable for their needs. We believe that it is more reliable than the Anderlohr model and easier to use than Gilbride's. The simpler models that use length of production break as the only independent variable are not supported by the data we have accumulated for this study. These and other models are described in more detail in Appendix C.

CURRENT STUDY RESULTS

Data

We obtained detailed schedule and cost data for seven programs that were shut down and restarted, three programs for which restart proposals were prepared, and an additional program for which extensive shutdown-task descriptions were provided.[6] The programs are listed in Table 2.1.

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[2]The consensus among contractors in a reconstitution workshop at RAND, March 25–26, 1992, was that whatever loss of learning is going to occur will occur in the first year or two after shutdown. Following that period, any further loss will be trivial.

[3]Anderlohr, George, "What Production Breaks Cost," *Industrial Engineering*, September 1960, pp. 34–36

[4]Neiss, J. A., and R. M. Selter, *GAPMODEL: A Computerized Production Break Model*, El Segundo, Calif.: The Aerospace Corporation, Report TOR-0089(4464-03)-1, December 1, 1988.

[5]Gilbride, Thomas J., Unpublished report, Naval Air Systems Command, Official Use Only.

[6]All contractors who provided data considered the cost data privileged information. Therefore, cost data have not been included in this report.

Table 2.1

Data Sample for Aircraft and Small Missile Shutdown and Restart

				Data Provided		
System	Contractor	Shutdown Tasks	Shutdown Costs	Restart, Non-recurring (N/R)	Restart, Recurring (Rec)	Restart, N/R +Rec
Actual Restart						
AGM-65A/B	Hughes	No	No		PQ[a,b]	
B-1	Rockwell	Yes	Yes		P	T[a]
C-5	Lockheed	Yes	No	ETPQ[a]	ETPQ	ETPQ
Jetstar	Lockheed	No	No		P[c]	
LAMPS	Kaman	Yes	No		P	
OV-10	Rockwell	No	No			ETPQ[d]
U-2R	Lockheed	No	No		P	
Proposed Restart						
CH-46(P)	Boeing	No	No		P[e]	
F-117(P)	Lockheed	Yes	Yes			P[e]
S-3(P)	Lockheed	Yes	No	ETPQ	ETPQ	ETPQ
S-3(P)	LTV	No	No	ETPQ	ETPQ	ETPQ
707	Boeing	Yes	No			

[a]E,T,P, and Q represent engineering, tooling, production, and quality assurance, respectively.

[b]Production data are for both fabrication and assembly. Quality data are for "test."

[c]ETQ restart data are not available by lot, resulting in single-point comparisons.

[d]Two production gaps. Assembly data only.

[e]Three production gaps. Final buy was a single lot, resulting in single-point comparisons.

Contractors provided data in various units. Most *shutdown* cost data are in dollars. The bulk of the *restart* costs, some of which are divided between nonrecurring and recurring costs, are in terms of labor man-hours for engineering, tooling, production, and quality assurance.

Material costs have not been addressed in this study because few data regarding materials were available, and most of the program costs are accounted for by the labor elements. The material costs referred to here exclude engines and avionics. They include raw materials, purchased parts, and high-value items necessary to make an airframe and its subsystems (hydraulics, electrical, environmental control, etc.). The relative importance in dollar terms is illustrated by the example in Table 2.2 of the estimated recurring costs of a production run of 100 new all-metal (i.e., no composites) fighter aircraft.[7]

The material element accounts for slightly less than 20 percent of the total cost; the labor categories account for the remaining 80 percent.

The 80–20 split represents the government's view of the (airframe portion) program. Today, there is considerable talk about programs involving 60 to 80 percent, or more, purchased material. Such statements are made from the prime contractor's point of view and reflect significant amounts of teaming plus addition of extensive avionics responsibility to the contractor.

Some of the systems in the current study go back to the 1950s, and the available schedule and cost data and descriptions are sketchy. Indeed, none of the systems is currently in production, although all are still in service. Only two programs, represented by three contractors, permit analysis of the nonrecurring costs of restart. However, all four major functional labor categories—engineering, tooling, manufacturing, and quality assurance—are covered.

We begin with the schedule implications of restart.

Table 2.2

Notional Recurring Cost Distribution for Production of 100 Fighter Aircraft

Cost Category	Estimated Costs ($ millions)	Percentage (%)
Engineering	603	21
Tooling	257	9
Production labor	1,289	45
Quality assurance	170	6
Material	559	20
TOTAL	2,878	100

[7]The example shows the estimated recurring cost of a modern, high-performance fighter based on estimating relationships presented in Resetar, Susan A., J. C. Rogers, and R. W. Hess, *Advanced Airframe Structural Materials: A Primer and Cost-Estimating Methodology*, Santa Monica, Calif.: RAND, R-4016-AF, 1991.

Schedule

How long does it take to restart production after the original line has been shut down for some period? Data were collected on seven programs that had actually experienced a production restart, plus four more for which restart was planned and a proposal made. This initial database consists entirely of aviation systems (aircraft, helicopters, and one missile), and the results are obviously not applicable to other systems, such as naval ships.[8] However, aviation systems constitute a major portion of the programs deemed likely candidates for a possible future restart (see Chapter Four).

Emphasis was placed on determining three intervals for each program:

1. From development go-ahead to delivery of the first production item in the original program
2. From contract start to delivery of the first production item during the restart program
3. From the last delivery in the original production run to the first production delivery in the restart program.

Comparison of the first and second intervals should yield some notion of the time saved by restarting a previous program instead of developing a new, replacement system. The third interval is one that has been deemed a significant parameter in some of the models used to estimate cost of a restart program. Figure 2.1 presents these intervals graphically. (Appendix D provides the specific data.)

Even this small data sample is not homogeneous. One of the programs (the Jetstar/C-140 light transport) was basically a commercial aircraft, with some items sold to the Air Force. Hence, the interval between development start and first production delivery is not strictly comparable with data from a purely military development program. Furthermore, that program experienced two gaps in production: The first was a deliberate pause of 13 months used to adjust

[8]Appendix B contains a brief discussion of production restart of naval ships.

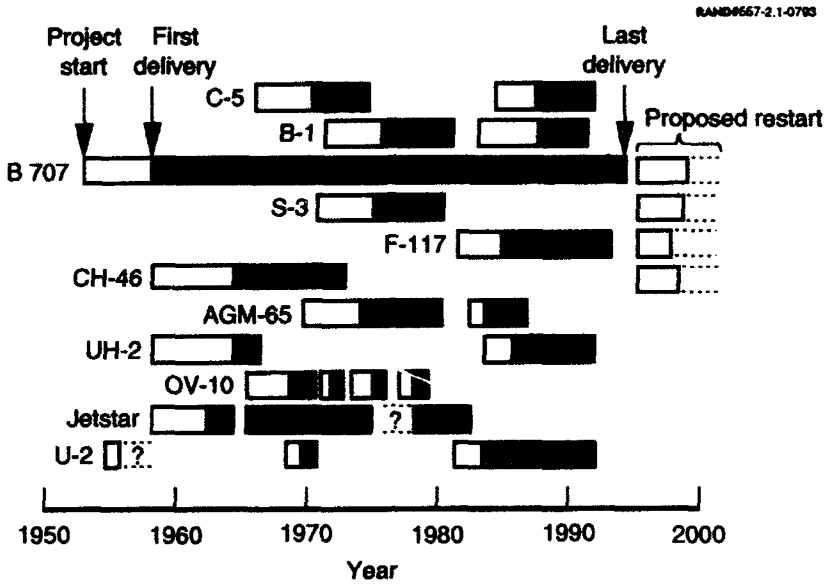

Figure 2.1—Production-Restart Schedules

inventory; the second preceded introduction of an improved model (Jetstar II). In neither case was it possible to determine a "restart contract date" equivalent to that of the other programs in the sample.

The CH-46 helicopter also evolved from a corporate-sponsored development program and went through an intermediate model configured for the Army before yielding the CH-46 design configured for the Marines. Thus, the rather long period of initial development is not comparable with that of the other programs.

Finally, the B-1 never achieved a true production status during the initial phase, and substantial development remained to be accomplished during the "restart" phase. That difference notwithstanding, the time from contract to first delivery during the restart phase is consistent with that of other programs.

Despite these variations in the data sample, the results suggest two broad interpretations. First, restarting a production program appears to take about one year less than producing the original system.

Second, for major aircraft systems, the restart time to first production averages about three years, which is consistent with the typical industrial lead time for long-lead components of such systems.[9]

Nonrecurring Costs

Of the programs surveyed for this study, contractors for only two, the C-5 (Lockheed) and the S-3 (Lockheed and LTV), provided separate data that permitted comparison of restart nonrecurring costs to original nonrecurring costs. The available data are the total nonrecurring labor hours recorded on the original program and those recorded (or, for the S-3, proposed)[10] on the restart program.[11] These programs are not necessarily typical.[12] Both the C-5 and S-3 programs were supported by the contractors after the completion of production and line shutdown: Spare parts were manufactured, and maintenance work was performed. Under such circumstances, it is probably reasonable to expect that overall nonrecurring labor costs for a restart program should be significantly less than those for the original program.

Table 2.3 presents the nonrecurring restart costs as a percentage of the original program costs in each labor category. Total nonrecurring costs for restart amounted to about 10 percent of those for original startup. In the various labor categories, analogous percentages range from a low of zero (LTV indicated no nonrecurring manufacturing labor for the S-3B restart) to a high of 19 percent on the

[9]In a new development program, delivery of the first production aircraft is not synonymous with initial operational capability (IOC). In a restart program, if there are no significant changes, the first production aircraft can be operational immediately. Compared on a readiness basis, restart of a program would be several years shorter than production of a new system. However, if there are significant changes or a major model change, a test program may be required prior to achieving IOC.

[10]S-3 restart proposals followed the C-5 restart. Undoubtedly, Lockheed drew from its C-5 experience to formulate its S-3 proposals.

[11]Note that the nonrecurring costs of only the shutdown and only the restart activities are not separately available.

[12]The C-5B had the new wing and some new cockpit avionics. The S-3B proposal had substantial amounts of new avionics. The U-2 is a good example of restarting without significant changes.

Table 2.3

Restart-Program Nonrecurring Man-Hours as a Percentage of Original-Program Nonrecurring Man-Hours

System	Contractor	Engineering	Tooling	Manufacturing	Quality	Total
C-5	Lockheed	8	17	14	16	11
S-3	Lockheed	9	19	4	11	10
S-3	LTV	2	9	0	110	5

Lockheed S-3 proposal (excluding LTV's 110 percent for quality). As a subcontractor to Lockheed, LTV built about half of the S-3 structure and, consequently, was not responsible for any weapon-system integration tasks; that may explain their lower percentage values. The 110 percent for quality stems from the fact that the absolute value of the man-hours was quite small for both the original and restart programs. It could reflect a minimum level of nonrecurring effort necessary to establish the recurring quality-assurance program.

Reestablishing the tooling and work flow, including inspection and test, is the major activity in restarting a production line that has been shut down and the tooling moved to storage. Consequently, it is not surprising that tooling and quality assurance have the highest percentage restart costs.

Both the C-5 and S-3 changed from "A" to "B" models after the original production program was completed. In general, the scope of a model change will dominate the amount of engineering required on a restart. Hence, the values shown in the table may be low for a more extensive model change than was experienced by the C-5 and S-3. Conversely, they may be high for no model change. The following program histories offer some insight into this issue.

Lockheed had already been awarded a contract for Full-Scale Engineering Development (FSED) of the S-3B, so the proposed S-3B restart engineering costs do not reflect all the costs associated with the model change. However, some model-change engineering costs are included because the proposal statement of work encompasses modification of two S-3A aircraft to S-3B configuration, plus Lockheed and Navy system test and evaluation activities.

Taken together, these conditions indicate that the S-3 engineering-restart percentage may be a little high for a restart with no model change but is probably very low for a restart that must pay for significant improvements.

There are too few data points to support a systematic method for predicting nonrecurring restart costs. The percentages shown indicate a range of baseline values that might be helpful for making estimates by analogy: The degree to which these values should be accepted or modified depends on how a new restart program compares with the C-5 or S-3 programs. In particular, specific consideration *must* be given to the extent of model change involved and the availability of data or physical assets from the original program.

Learning-Curve Analyses

To compare all labor categories and programs on a consistent basis, best-fit learning curves were determined for the logarithms of unit (lot) man-hours versus logarithms of lot midpoints, using the ordinary least-squares regression method. This approach is consistent with the straight-line unit-cost-curve theory.[13] The resulting best-fit learning curves were used to compare original programs and restart programs, as described later in this section.

When a production program is stopped and restarted, some loss of learning is anticipated. That is, the cost of the first restart unit will be higher than that of the last original-program unit. Figure 2.2 shows a typical set of cost data for such a program. Replotting data from the quality-control curve in Figure 2.2 as two separate sets of data, with the restart treated as a new program, results in the two curves in Figure 2.3. Figure 2.3 indicates that quality-control restart man-hours for the first unit and the rate of decline are less than those for the original program.

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[13]For a detailed description of learning-curve theory, see Asher, Harold, *Cost–Quantity Relationships in the Airframe Industry*, Santa Monica, Calif.: RAND, R-291, July 1956.

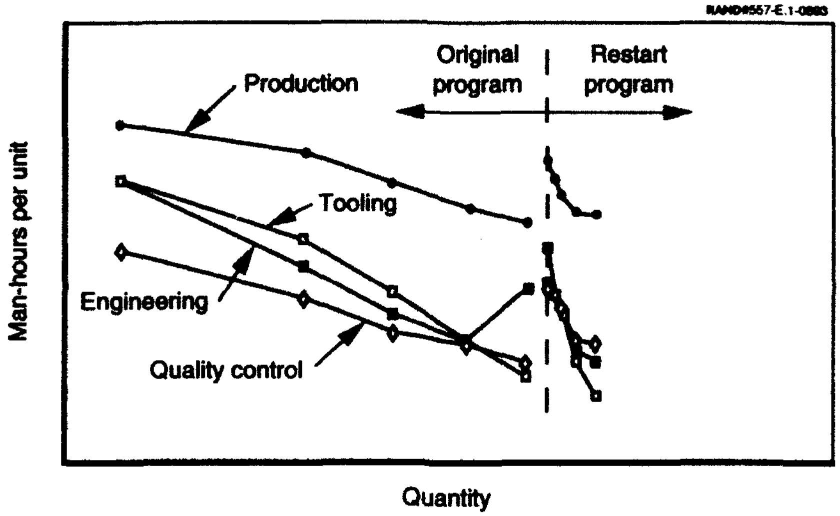

Figure 2.2— Original and Restart Man-Hours per Unit Versus Quantity, Plotted Sequentially

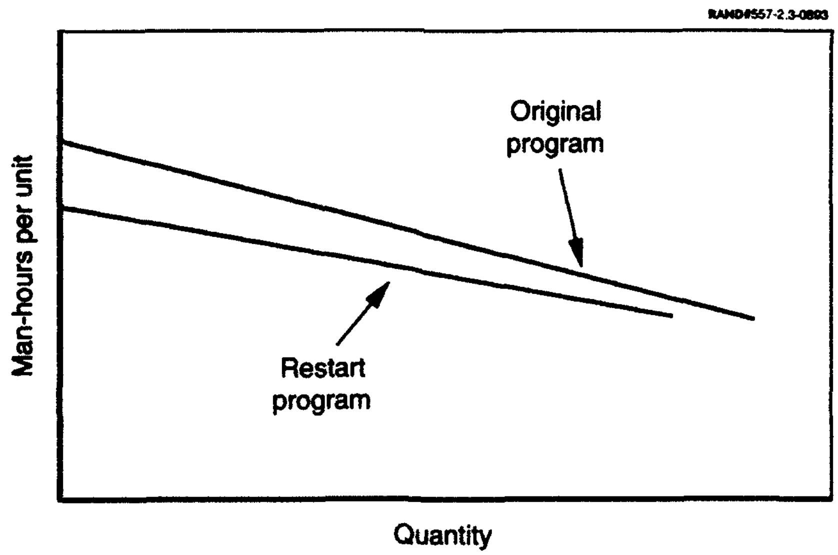

Figure 2.3—Quality-Control Man-Hours per Unit Versus Quantity, Plotted Separately for Original and Restart Productions

The learning-curve analysis provides those quantitative data relating to cost issues that managers must consider when weighing the advantages and disadvantages of production restart. For example, they would like to know:

- The ratios of the restart first-unit costs to the original first-unit costs
- The slopes of the original and restart curves
- The quantity at which the unit cost on the original curve is equal to the first-unit cost of the restart curve.

We examine each of these to see whether any consistent patterns emerge that offer guidance for future production-restart programs.[14]

Taken together, the data indicate overwhelmingly that restarts begin at lower first-unit costs and proceed on shallower curves than their corresponding original programs. Excluding the B-1, which did not achieve full-production capability in the original program, 37 comparisons of original and restart learning curves *all* have restart first-unit costs lower than the original and restart curves shallower than the original. In addition, of ten restart cases for which only a single data point is available instead of full curves, nine have points below the original learning curves and the tenth is on the original curve.

Of the 37 learning-curve comparisons, 17 are for programs that include both recurring and nonrecurring costs. In some cases, recurring and nonrecurring were combined; in others, they were identified separately. The results presented and discussed in this section are for the 20 recurring best-fit curves. All the learning-curve results are presented in Appendix E.

Table 2.4 summarizes the results of the ratios of restart first-unit costs to original first-unit costs. On average, recurring production

[14]It has been suggested that the cost of the final unit produced in the original program should have some independent explanatory power. That cost is a function of production quantity, and production quantity is different for each program in the data set. Consequently, we would not find a consistent relationship between original last-unit cost and restart first-unit cost.

Table 2.4

Restart First-Unit Cost as a Percentage of Original First-Unit Cost, Recurring Costs

Labor Element	Range of Observations										Average
Engineering	6	28	53								29
Tooling	18	48	55								40
Production	29	35	38	40	53	54	55	61	76	82	52
Quality	35	48	51	74							52

and quality-assurance labor restart at approximately 50 percent of the original first-unit cost, whereas engineering and tooling restart at approximately 30 and 40 percent, respectively. The number of observations for engineering, tooling, and quality is small, and the averages may not be representative because of a single, relatively high or low observation.

Original and restart slopes are presented in Table 2.5. In all cases, the average restart slopes are shallower than the original slopes.[15] The difference is greatest for engineering (a delta of 18, from 61 to 79). The other differences are roughly of the same magnitude (tooling: a delta of 5, from 69 to 74; production: a delta of 8, from 80 to 88; and quality: a delta of 8, from 76 to 84).

Table 2.6 summarizes results for the quantities at which the unit cost on the original curve is equal to the first-unit cost of the restart curve. Only two observations are greater than unit 20 (engineering, unit 51; and production, unit 32); indeed 16 of the 20 observations indicate restart at an equivalent to unit 10 or lower. Although this measure is frequently referred to in discussions regarding production restart, it provides no information beyond what is contained in the original-program slope and the ratio of first-unit costs: These two numbers uniquely determine the quantity.

[15]A shallower restart slope means that, at some quantity, a linear projection of the restart curve will cross the original curve, thus giving higher costs. Aerospace-industry analysts argue that, in reality, the two curves become asymptotic and do not cross. While that is generally true, our data show that in a few instances a crossover did occur.

Table 2.5

Original and Restart Slopes (%), Recurring Costs

Labor Element	Range of Observations	Average
Original		
Engineering	59 61 64	61
Tooling	58 66 82	69
Production	74 75 77 77 79 80 81 87 92	80
Quality	73 74 75 83	76
Restart		
Engineering	65 77 94	79
Tooling	67 72 83	74
Production	83 84 85 85 86 87 89 91 93 94	88
Quality	80 83 85 87	84

Table 2.6

Quantity at Which the Unit Cost on the Original Curve Is Equal to the Restart First-Unit Cost, Recurring Costs

Labor Element	Range of Observations	Average
Engineering	4 7 51	21
Tooling	4 8 9	7
Production	2 5 5 7 9 9 10 11 17 32	11
Quality	3 5 6 10	6

In summary, the data and analyses in the current study show that several aircraft programs have been successfully restarted with shorter schedules and lower nonrecurring and recurring costs than were incurred on the original programs. As long as the conditions in the aircraft industrial base do not change significantly, restarting an aircraft program that has previously achieved full-production capability and then has been shut down should be significantly less expensive than the original or a comparable new program.

WHY THE COST DIFFERENCE BETWEEN THE ORIGINAL PROGRAM AND THE RESTART PROGRAM?

As our analyses have shown, restart cost-improvement curves have a flatter slope and a lower unit-1 value. To understand this outcome, we compared qualitative characteristics of the restart and of the original programs.

A survey of the firms revealed that restart programs typically have fewer problems. Original programs almost always experienced severe difficulties with late and incomplete data that sometimes led to errors in the engineering and tooling drawings and subsequent producibility and interface problems. Such difficulties are much less likely to occur in a restart program; when they do, their magnitudes seem to be significantly less, depending on the extent of the changes. In manufacturing, too, normal startup difficulties (e.g., incomplete planning, tool difficulties, small fabrication lots, and part shortages) translate into higher costs early in a production run. However, in restart programs, corporate memory substantially mitigates such difficulties. Process improvement and employee learning are exceptions, because during the interim the line is closed, the firm's manufacturing processes will continue to evolve and improve from work on other products. As a consequence, many of the processes employed during the restart program may be new to management, shop foremen, and the workforce. And if the production gap is very long, a "new" workforce may be involved.

One of our goals was to identify cost and schedule variables correlated with restart-program first-unit costs and slopes. Regression analyses were performed for four subsets of the 37 learning curves discussed above: the recurring-cost cases for the aircraft programs only, the recurring-cost cases including the AGM-65, the *total-cost* (nonrecurring plus recurring) cases, and the combined-sample set of all 37 observations.

For recurring costs, the significant determinants of restart first-unit cost were the original first-unit cost and the original slope. For the total and combined-sample cases, the length of the production gap also entered as a significant explanatory variable. This difference suggests that the length of the production gap has little to do with recurring costs as production resumes, but does influence nonrecurring costs. For the restart-slope regressions, only the original slope and the ratio of restart to original first-unit costs were significant variables.[16] The regression equations are presented in Appendix F, "Regression Analyses."

CONCLUSION

In examining restart cost and schedule experience of aircraft programs and a missile program that have been restarted, we necessarily drew our data from a historical environment with a large and continuing program and workforce base. If the industry falls into serious decline and a generation of skilled workers is allowed to dissipate, restarting a production line might be less practical than recent experience has indicated.

In the next chapter, we turn our attention to preparing for a restart and to identifying those policies and procedures that will enable production lines to be reopened quickly and at least cost to the government.

[16]The ratio of restart to original first-unit cost would not be known for a restart program still under consideration. However, the restart first-unit cost equation given in Table F.1, Appendix F, can be used to determine an estimate that can be divided by the original first-unit cost to obtain a value for the ratio to be used in the restart-slope equation.

Chapter Three

PREPARING FOR PRODUCTION RESTART: SMART SHUTDOWN

In the past, when a major system's production lines were shut down, producers and services paid little attention to shutting down production in a manner that would enable that line to be quickly and inexpensively reopened. Indeed, for some manufacturers, incentives were to ensure that the *production line could not* be reopened and possibly compete with a new program. Most often, producers and the services were interested in shutting the line quickly and at the least cost possible. After all, new systems were always just around the corner, and the pressure to keep up with what was then the Soviet Union required looking forward, not standing still or looking backward.

Today's environment is quite different. As the threat to U.S. security is lessened and the defense budget is reduced, many defense planners realize that current defense systems may be sufficient, both in numbers and quality, for some time. But concern and uncertainty still exist, and the ability to reopen closed production lines is an important option. For planning purposes, we must assume that essentially none of the people currently performing the myriad tasks will be available when the restart is performed. All the actions to preserve information that will assist new workers to pick up where the previous ones left off, with a minimum of confusion and wasted effort, must be identified and accomplished.

To achieve this outcome, we need to answer four questions:

- What needs to be preserved?
- What is the cost?
- When should actions be taken?
- What are possible influences beyond program control?

These issues were addressed as part of a reconstitution workshop held at RAND, March 25–26, 1992, and attended by prime aircraft manufacturers. The results of that workshop are summarized below.

WHAT NEEDS TO BE PRESERVED?

In the past, shutdowns have essentially called for auditing all the various aspects of engineering data for completeness, then locking them up "in place." The purpose of shutting down production activity smartly is simply to ensure that a new group of people sometime in the future will find a complete, accurate, and usable database with which to start.

Useful Items

A list of items deemed useful for restart is shown in Figure 3.1.[1] In the engineering category, drawings are clearly important, as are design specifications for all structural and subsystem elements. Material and process specifications and test documents are as important as drawings themselves. A careful audit of engineering test and development hardware is also required. For example, the Iron Bird hydraulic and mechanical test equipment may well be worth preserving and keeping minimally functional. Integration laboratories for electronics and wind-tunnel test models must be similarly examined. The full-scale static and fatigue test articles would be expensive to retain but, depending on the program, might be worth-

[1]This list was generated at the RAND reconstitution workshop. The list was used during subsequent data-gathering visits to contractors who were not at the workshop. Without exception, firms that we met with agreed that this list contained the basic items needed for restarting production.

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Engineering

Drawings
Test procedures
Configuration documentation
Updated drawings
Software source code
– Mission equipment
– Test equipment
Mockups
Test articles
Iron Bird
System integration lab
Qualification test data
Engineering analyses
– Stress, loads, drag
– Flying qualities
– Propulsion, etc.

Tooling and Manufacturing

Fabrication and assembly tools, "one each"
Job description
– Videos, etc.
Tool designs
Special test equipment
Master gauges
NC source data
Manufacturing plans and schedules
Machine accessories
Unique machine tools
Indentured parts list
Detailed build plans
Organization chart with crew sizes

Material

Bill of materials
Supplier list
Alternate suppliers (qualified)
Long-lead materials
Critical materials list plus sources
Make-or-buy plans

Quality

Test procedures
Qualification test data
Production inspection records
Source inspection records
Quality-defect records

Other

Key personnel list
Lessons learned
– Training
Contracts and amendments
Auditable cost records
Cost accounting disclosure statement
Facilities

Figure 3.1—Items Useful for Restart

while. Potentially valuable would be measures to save all basic technical reports, such as the stress analysis, drag analysis, flying-qualities analysis, propulsion analysis, and loads analysis, together with basic design specifications for hydraulic, electrical, and mechanical systems.

In manufacturing, preservation of tools and fixtures for fabrication, subassembly, and final assembly is helpful and has sometimes been done in the past. Also important would be the acquisition and careful organization of photographs and videos showing every detail of the manufacturing operations, particularly the final assembly. Of importance on the paperwork side would be to inventory and update drawings and documents with all changes and store an accurate set of Production Inspection Record (PIR) books. These documents are literally the "how-to-build-it" instructions and include quality criteria. Together with the full change-incorporated PIR books, a complete, updated set of Production Illustration (PI) drawings should be preserved. Functional test documents and procedures, together with updated and change-incorporated final checkout procedures, are also valuable. Production flight records on the last several ships should be carefully preserved, including data on corrective actions necessary for delivery.

Of all the functional areas for which additional attention at shutdown could facilitate startup, perhaps the most important is in procurement, because, as viewed by prime contractors, modern weapon systems can be 60 to 80 percent purchased items.[2] The complete set of procurement specifications, including the most recent changes, for all the subcontract and purchased equipment in the weapon system should be audited for completeness before lockup. A complete set of procurement data on the last production lot or two, including quantities per ship, lead time, unit price, delivery acceptance criteria, etc., would be invaluable to a new group of people starting up years later.

Also important would be an analysis, working with a selected group of the critical suppliers, of each and every item from raw material to sophisticated purchased equipment to determine its survivability in the marketplace and the likelihood of its availability in the future. The objective would be to determine which items might deserve funding support or other assistance to ensure availability when needed for startup or whether a substitution would be more cost-effective.

A final significant consideration for shutdown documentation is in financial data and records. Fabrication cost-data by part, with standard and actual hours achieved in at least the last two lots, are valuable. Similar information should be edited, assembled, and carefully preserved for both sub- and final-assembly work. Learning curves, not simply for overall ships but also for fabrication, sub-, and final

[2]See comments in Chapter Two under "Current Study Results: Data."

assembly, are important. Cost data for all procurement and subcontract work should be compiled, edited, and preserved. These data will facilitate startup-cost estimation and establish budgets and man-loading expectancies for the new workforce in later years.

A final consideration is that because of continual change in the aerospace industry—people leave, departments are reorganized, plants move, etc.—documents are sometimes lost after a few years. Prudence dictates that more than one copy should be made, and the copies should be stored in different locations.

Necessary Items

Whereas Figure 3.1 identifies what needs to be preserved, it does not provide a sense of which are the most important elements. That sense is determined by identifying the degree of need and associated costs. Degree of need was broken out into two categories:

1. Required, even if low probability of restart
2. Optional (nice to have).

The magnitude of cost is almost always small—tens or hundreds of thousands, at most a few millions of dollars—and linked to the storage and preservation of large, bulky items. Figure 3.2 designates which of these items seem essential to restart a production line and which have modest costs associated with their preservations. (Relative importance is noted by "R," for required, and "O," for optional. Relatively costly items to preserve are noted by a dollar sign, $.) The relatively costly items are those that are essential to a quick, inexpensive restart. Generally, if these items are not stored, a very high cost and possibly a substantial time delay, as well as increased program risk, could be associated with replacing (re-creating) them. Optional items are not as important, although many of the optional items under "Engineering" may be more useful if the restart involves significant design changes.[3]

[3]As an example, the 1982 proposal to restart the S-3 line included modification of the original-program static test article to serve as the restart engineering mockup.

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Engineering

R Drawings
R Test procedures
R Configuration documentation
O Updated drawings
R Software source code
– Mission equipment
– Test equipment
O$ Mockups
O$ Test articles
O$ Iron Bird
O$ System integration lab
R Qualification test data
R Engineering analyses
– Stress, loads, drag
– Flying qualities
– Propulsion, etc.

Tooling and Manufacturing

R$ Fabrication and assembly tools, "one each"
O Job description
– Videos, etc.
R Tool designs
R Special test equipment
R$ Master gauges
R NC source data
R Manufacturing plans and schedules
O$ Machine accessories
R$ Unique machine tools
R Indentured parts list
R Detailed build plans
O Organization chart with crew sizes

Material

R Bill of materials
R Supplier list
R Alternate suppliers (qualified)
O$ Long-lead materials
R Critical materials list plus sources
R Make-or-buy plans

Quality

R Test procedures
R Qualification test data
R Production inspection records
R Source inspection records
O Quality-defect records

Other

O Key personnel list
O Lessons learned
– Training
R Contracts and amendments
R Auditable cost records
O Cost accounting disclosure statement
O$ Facilities

R = Required, even if low probability of restart.
O = Optional; nice to have.
$ = Relative storage cost is high.

NOTE: Many of the above items are facility-specific and lose some value if another facility will be used.

Figure 3.2—Relative Importance of Items for Production Restart

Note that, although nearly two-thirds of the items listed (26 out of 40) are considered to be very important to a restart, only three are likely to incur substantial costs, albeit quite modest relative to original acquisition costs: fabrication and assembly tools, master gauges, and unique machine tools. All other items are relatively inexpensive to assemble and store. Thus, it appears that a rather robust program of preparing for future production restart should be relatively inexpensive.

Who Pays These Costs?

Who pays these costs is an important consideration: Without a commitment for production, primes or subcontractors have little, if any, incentive to leave in place or pay to store large, bulky items that take up valuable floor space or incur cost that cannot be charged to an ongoing contract. Even though these costs are small compared with the original-program costs or cost to procure again, nonreimbursable costs detract from the firm's bottom line. Thus, if the probability of restart is low, as it has been in the past, firms are unlikely to incur such storage costs on their own. One could argue, however, that in a procurement environment where production restart is more common, a firm might choose to invest in a restart capability as a means of increasing the likelihood of restart. Presumably, decisionmakers would consider restart more favorably when a restart capability exists. In any event, when the restart option is selected, the costs are small compared with the immense savings to be realized.

Such cost avoidances are difficult to quantify after the fact. However, at a cost of about $10 million and at its own expense, Rockwell stored special-purpose and one-of-a-kind B-1A tooling. Because of this stored tooling, Rockwell estimated cost avoidance on the order of $1 billion in tooling costs for the B-1B program.

WHEN SHOULD ACTIONS BE TAKEN?

Planning for an orderly shutdown can occur anytime in the acquisition process but in no event later than placement of the last production order. Some vendors and prime-contractor shops complete their work several years before the final end-item is delivered. For those systems for which DoD is willing to make an investment to preserve the option of restarting a production line, as soon as it is known that the production line may be shut down, advance planning should begin to ensure that tools, equipment, engineering drawings, specifications, paperwork, and other essential data are inventoried and stored in such a manner that the program could be restarted with minimal effort. Tools from subcontractors should be inventoried and stored as the line is being shut down, and other actions should be taken as discussed above.

During shutdown of one recent program, a large aerospace firm established an independent team for preservation of the data, tools, drawings, management systems, etc., which was an important step in reconstituting a production capability. The team worked on this task for about 18 months. Total team size was about 50 to 75 people dedicated to restart planning and preservation and 25 to watch and document the last production unit. They followed the last unit through every step of the production line, capturing all planning documents, documenting all differences between plans and production, developing checklists, and videotaping critical operations. The team surveyed all the production workers for what they would pass on. In addition, the team captured all the controlled tooling and shop aids—Mylars, patterns, etc.

Of course, the vast amount of engineering data involved is always being changed; at a given time, thousands of drawings and specifications may not be completely current relative to change incorporation. Should every drawing and specification have all changes incorporated before filing? Should the complete drawing "tree" structure be checked for completeness and every hole be filled prior to shutdown? Opinions vary. Some argue that the system will continue to be modified and upgraded throughout its operational life, and that the drawings will have to be updated anyway when the line reopens. Each program is unique, and trade-off analyses should be conducted to decide whether to put away drawings, procedures, etc., as is or only when thoroughly updated and fully reflective of the last ships manufactured. When a high probability of restart exists, a small team (10–15 people) could be maintained for a major weapon system. Over time, they would keep the drawing base current by tracking, analyzing, and cataloging all service-initiated changes.

Such shutdown activities would add to shutdown cost; that cost, in turn, must be weighed against the time and cost savings on startup with new people trying to do the same jobs but without the current skill, knowledge, and program experience.

WHAT ARE POSSIBLE SIGNIFICANT INFLUENCES BEYOND PROGRAM CONTROL?

As a program is shut down, those involved in the process need to be aware that the government and contractor environment will change. Military standards, Defense Acquisition Regulation (DAR) and Federal Acquisition Regulation (FAR) requirements, local and state taxes, and health, safety, and environmental regulations may all be quite different in a few years. The contractor environment is also dynamic: Accounting systems, organizational structure, methods, systems, procedures, and manufacturing process could be quite different. In addition, the weapon system could be produced in another location, in a different facility, or with a completely new workforce. Such possibilities are unpredictable; nevertheless, those responsible for shutting down production and deciding what to preserve should be sensitive to them.

Chapter Four

IDENTIFYING CANDIDATE SYSTEMS FOR RESTART

At this point we have established with some confidence that production restart has been successful in the past, saves both time and money compared with putting a new system into development, and is facilitated by planning during shutdown. An important question remains: What is the range of systems for which reconstitution might be appropriate? We need to answer this question for two reasons. First, it helps us to understand the degree to which restart might satisfy the broader objective of force reconstitution; second, it helps focus on the more detailed, system-specific factors affecting restart practicality. Our approach in this phase of the study was to prepare a set of selection criteria, then to apply those criteria to a representative list of candidate systems.

CRITERIA FOR IDENTIFYING CANDIDATE SYSTEMS

Not all weapon systems are candidates for production restart. The decision to restart would occur in the future and would depend on specific world conditions at that time. The focus of this research is on the decision to preserve the *ability* to restart.

Historically, planning for possible production restart has not been considered seriously until a production run is nearing its end. In the future, that policy may change because the possibility of restart can profoundly affect basic program planning, primarily the quantity of systems procured. For example, the Air Force assumes a certain attrition rate for aircraft, and procurement plans include enough aircraft to keep the squadrons at full strength after attrition has occurred. With planned restart, those aircraft might not be produced until needed, thus deferring and possibly avoiding their cost.

An even stronger argument could be made for deferring the production of items, such as air-to-air missiles, that go into storage until needed. A military service could plan to restart the production line every few years to keep the stockpile at a prescribed level and to be ready for a possible surge in demand. Deferring procurement would mean avoiding procurement in some cases, and force-wide the savings could be substantial.

These possibilities assume that restart is shown to be practical in terms of time and cost. Early planning for restart, however, would affect both. A firm could adopt a flexible manufacturing technology that is suitable for the original production program and can be easily reconstituted in the event of restart. Large tools could be designed to be easily dismounted for storage and easily reassembled. A contractor's make-or-buy decisions would be affected: Given an early indication of restart, both the purchasers and producers of weapon systems could explore measures that would reduce the time and cost associated with after-the-fact decisions. And, if restart is treated as a normal procurement-policy option, the importance of the cost issue would be diminished. Finding the money needed for the activities discussed in Chapter Three would not be difficult in a multibillion-dollar production program.

Early planning for production restart is a new concept, however. Its ramifications have not been explored, and such an exploration is beyond the scope of the present study. The first criterion in the four-step process displayed in Figure 4.1 deals only with the timing of the decision to preserve a restart capability.

The process is laid out as a series of questions. The first three steps relate to the restart-preservation decision; they consider the current acquisition status of the candidate systems, their projected force levels, and the availability of alternative systems to satisfy the military need. The fourth step focuses on the restart decision, which would address such issues as specific threats and environments, costs, schedules, operational lives, etc. Each step is discussed below, followed by a sample application of the first three criteria to 115 major weapon systems representing all military services. The fourth cri-

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Criterion I: Can Review of System X Be Postponed? — If no, proceed

- Is system still in development?
- Are procurement appropriations now programmed beyond 1995?

Criterion II: Is Future Demand Beyond Programmed Levels Plausible? — If yes, proceed

- Are replacements required because of peacetime attrition or combat consumption?
- Is increase in force size likely?

Criterion III: Could Another System Be Substituted? — If no, proceed

- Is a similar system now in production?
- Will scheduled follow-on soon be available?
- Are units available in storage?

Criterion IV: Would Restart Be Practical?

- Is the system now operational?
- *Are restart schedule and costs acceptable?*

Figure 4.1—Restart Criteria

terion is not applied because it depends on the future threat and environment. We emphasize that in presenting these criteria our intent is not to identify or recommend systems for future production restart. It is, rather, to illustrate the kind of systematic approach needed to identify programs as candidates for future restart.

Criterion I: Can Review of System X Be Postponed?

A well-known maxim of management is that decisions should not be made before they become necessary; otherwise, some useful information might be missed. Likewise, we consider it unnecessary and inappropriate to judge the likelihood of restarting the production of some system long before the production ends, or even begins. Therefore, we first screen out systems that are still in development or for which procurement funding is currently programmed for years beyond 1995 (dates used here are examples only). Periodic reviews of their status and prospects would be necessary to identify candidates for future production restart. The systems that remain in the candidate list consist of those that have recently ended their production or for which production is scheduled to end during the first half of the 1990s.

Criterion II: Is Future Demand Beyond Programmed Levels Plausible?

Having focused on those systems already out of, or soon to go out of, production, we next examine the likelihood that the current estimate of planned stock levels for a particular system might turn out to be wrong. More specifically, we try to identify how likely it is that some future contingency will lead to a need for substantially more than the quantities carried in current force and financial plans. That is, we examine only threat-driven needs in this study. Other factors, such as the need to preserve a critical industrial capability or to support allies, might play an important role in some production decisions, but they are outside the context of this research.[1]

Opinions about future needs are subjective, and different observers may arrive at different conclusions. It seems useful, however, to make some broad, non-contingency-specific distinctions among systems on the basis of possible changes in quantities needed. More specifically, we must identify those systems for which it is plausible that the United States might face a shortfall under either of two scenarios.

Replace Peacetime Attrition and Wartime Consumption. When a military system is kept operational for many more years than were originally envisioned, a point may be reached, because of attrition, at which production restart would be desired to expand the force size. Or, for the more obvious case, if the country becomes engaged in warfighting on a substantial scale, some elements of the force will be

[1]A special case would be those programs in which production quantity was reduced because of budget problems but for which the operational requirement still exists. Such programs could have a high probability of restart.

lost as a result of consumption or combat attrition. For example, in the recent Persian Gulf War, the U.S. forces expended a major portion of their stocks of precision-guided munitions. Replenishing those stocks will require procurements that were not envisioned before the start of that war. Frontline combat systems—fighter aircraft, armored vehicles, etc.—are obvious candidates. Conversely, some kinds of systems are expected to be relatively immune to either consumption or attrition; space assets are an obvious example.

Increase Force Size. Currently planned force levels are based on today's perceptions of worldwide economic and political environments. Because those perceptions can change in unexpected ways and over short periods of time,[2] the United States might need to increase the overall level of standing military forces. Such changes affect some kinds of equipment more than others, and the challenge is to identify those systems most affected by increases in force levels.

Even without such an increase, shifting world events could lead to a different mix of weapon systems that would call for quantities greater than those in current plans. Admittedly, any estimate, even one based on detailed projections of future contingencies, is speculative. We include the possibility of shifting world events mostly for the sake of logical completeness, but have made little use of it in applying the criteria in the following section, "Application of Criteria: The Screening Process."

Criterion III: Could Another System Be Substituted?

If we conclude that additional quantities of a particular weapon system might be needed in the future, the next step is to examine possible sources. Overseas sources may be an option in some cases; however, they tend to be very situation-dependent and fall outside the mainstream of defense procurement. The possibilities for domestic sources fall into three general categories.[3]

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[2]Needs can change faster than the capacity to produce. Restarting production of even such simple items as ammunition typically takes at least 18 months, whereas more complex systems, such as armored vehicles and flight vehicles, require three to four years before initial production quantities appear.

[3]We exclude the case where the need for additional systems arises before a production line has been closed.

Produce a Substitute System. Sometimes an acceptable alternative to the needed system might be in production. If so, it might be appropriate to substitute that system for the one deemed in short supply. Usually, the decision on such a substitution will depend on details of the new environment, and the results cannot be predicted with confidence. Where it appears that an alternative system would be more widely applicable, this option is given greater weight.

Draw from Storage. It is common practice to save excess systems for some substantial period of time after they are phased out of the active service. Armored vehicles, naval vessels, and aircraft are currently stored, some in large numbers, as are expendables such as ordnance items. As the present force reduction proceeds, some excess items with not-yet-outdated capabilities will be added to the stored stocks. If adequate supplies of the needed item are in storage, drawing from such stocks would likely be the most obvious way of satisfying unplanned needs. In some cases, it may be appropriate to upgrade or refurbish the stored item before putting it into service.

Produce a Scheduled Follow-On System. New systems are continually being developed and produced to replace obsolete designs. If such a new system is sufficiently far along in its development process that availability can be confidently projected, it might be appropriate simply to wait for the new system. For example, if additional transport aircraft were needed, it might be appropriate to wait until the C-17 achieves production status. Such a wait would typically involve some risk since budget pressures can force the termination of even the most promising programs. That risk would have to be weighed against the time (and money) involved in restarting production. As in the case of producing substitute systems, waiting for a follow-on will depend on the details of the particular case.

Criterion IV: Would Restart Be Practical?

If the system needed is unique (i.e., there is no close substitute), none is available from storage, and no replacement is expected in the near future, restarting a production line might be the preferred option. Questions of requirements and practicality must then be addressed: the threat and environment, cost, when the units would be available, whether the number to be produced would justify the investment, and whether the new units would have a sufficient operational life before becoming obsolete. Answers to those questions depend on the specific system under consideration and the timing and motivations for restart. In our illustrative screening in the following chapter, we make no attempt to predict the outcome of the practicality examination.

It is worth noting, however, that one issue of practicality can be assessed: Is the system currently operational? This question is important for at least two reasons. First, if a system is operational and if the system is a vehicle or other item that requires maintenance, repair, and overhaul, then many of the industrial suppliers necessary to support production are still in business, supplying spare parts and maintenance services to the system. This being true, restarting a production line becomes a much more realistic and practical matter than when all, or most, of the original suppliers have quit building the kind of items needed. Second, the existence of an operational cadre, plus the supporting infrastructure within both the service and industry, means that introducing additional units into the inventory should go much more easily than if the system is completely out of operation. We include this practicality criterion in the screening process.

APPLICATION OF CRITERIA: THE SCREENING PROCESS

To obtain a first-order estimate of the range of systems for which production restart might be an interesting option, we applied the criteria described above and displayed in Figure 4.1 to lists of major systems in each service. The candidate lists included all systems covered by *Selected Acquisition Reports* over the past 20 years that have not subsequently been canceled, superseded by later models, or incorporated in other programs. To those we added a few systems that seemed appropriate for such a review but that were not covered by SARs, such as the B-2 bomber. This initial list could be expanded to cover such items as munitions and possibly other systems that are not SAR-level but still represent major procurement actions.

The results of our initial screening are summarized here and detailed in Appendix G. Summary tables for each service show the results of the various screening steps.

We emphasize that *these results are illustrative.* The screening process involves many judgments, and a broad range of knowledge about current service plans is needed for some systems. Our main goal was to provide both reasonably complete coverage of systems and a *framework* for analysis. A review and critique by experts in each of the three services is needed to ensure accuracy and full compliance with current policy.

Army Systems

Table 4.1 presents results of the preliminary assessment of Army systems. Nearly two-thirds of the Army systems are either still in development or are currently programmed for procurement beyond the 1995 cutoff date adopted in this study. Of the remaining 11 systems, two (the AH-64 and OH-58D AHIP) are affected by the projections for the AH-66. Given current plans for extending the AH-66 Engineering and Manufacturing Development (EMD) phase beyond the five-year budget planning cycle, the availability of that system to augment and/or replace either of the current combat helicopter systems is uncertain.

Our judgment is that there are considerable opportunities for upgrading the AH-64 and that the Apache will likely remain as a major force element well into the next century. We therefore ranked the AH-64 as a candidate for possible production restart, should the need arise for expanding the Army combat helicopter force, even if the AH-66 is put into production. The status of the OH-58D, an older design, seems more questionable because the early production versions of the AH-66 might be available soon enough to make restarting the OH-58D inappropriate even if additional scout helicopters are needed in the near future. Considerations for the other possible candidates are as follows:

- AH-64
  - Possible high consumption rate

Table 4.1

Summary Assessment of Army Systems

System	Rejected at Criterion I: Still in EMD	Rejected at Criterion I: Funding Programmed Beyond FY95	Rejected at Criterion II	Possible Candidates for Restart
AMS-H	✓			
ADDS	✓			
ASM	✓			
ATCCS-AFATDS	✓			
ATCCS-ASAS[a]	✓			
BAT	✓			
FAADS-LOS-F-H-/ADATS	✓			
FAADS-C21	✓			
RAH-66	✓			
Longbow Apache Modification	✓			
Longbow Hellfire	✓			
SADARM	✓			
ATCCS-MCS		✓		
ATCCS-CSSCS		✓		
FAADS-LOS-R		✓		
FMTC		✓		
JSTARS-GSM		✓		
MLRS		✓		
Patriot		✓		
SINCGARS		✓		
UH-60/MH-60		✓		
FHTV (PLS)			✓	
Hellfire			✓	
M1 tank			✓	
MSE			✓	
TOW-2			✓	
AH-64				✓
ATACMS				✓
Bradley FVS				✓
CH-47/MH-47				✓
OH-58D (AHIP)				✓
Stinger-RMP				✓

[a]These systems are involved in ongoing review by the Defense Department, and their placement on this chart is subject to modification. However, because they are excluded from the production-restart analysis, any change in their status or assignment should not affect the results of the restart analysis.

- — Present program satisfies current needs, but considerable opportunities for upgrading exist
- — Availability of follow-on system uncertain.

- ATACMS
  - — Possible high consumption rate, but procurement program based on European scenario yields large stocks
  - — Modern, effective weapon; future upgrades likely
  - — No substitute available or planned.
- Bradley FVS
  - — Potential for combat attrition
  - — Modern, effective weapon
  - — Might be utilized in additional applications
  - — No substitute available or planned.
- CH-47/MH-47 helicopter
  - — Potential for combat attrition
  - — Additional units could be required to support SOF and other new missions as Army seeks enhanced mobility
  - — No close substitute or follow-on available.
- Stinger-RMP missile
  - — Possible high consumption rate
  - — Present program satisfies current needs, but changes in overall responsibility for air defense might increase needs for Stinger-type weapons
  - — No substitute available or planned.

Navy Systems

Table 4.2 shows the preliminary assessment of Navy systems. Major ships pose the most difficult questions here, especially nuclear-powered submarines and aircraft carriers. Additional ships of those two

Table 4.2

Summary Assessment of Navy Systems

System	Rejected at Criterion I: Still in EMD	Rejected at Criterion I: Funding Programmed Beyond FY95	Rejected at Criterion II	Possible Candidates for Restart
Advanced air–air missile	✔			
Advanced interdiction weapon system	✔			
Airborne self-protection jammer	✔			
Sea Lance	✔			
Fixed distribution system	✔			
Family of unmanned vehicles	✔			
V-22	✔			
AMRAAM		✔		
AN/UYS-2		✔		
DDG-51 class		✔		
EA-6B		✔		
F/A-18		✔		
LHD-1 class		✔		
MK-48 torpedo upgrade		✔		
MK-50 torpedo		✔		
Phalanx CIWS		✔		
P-3C		✔		
SH-60/SH-60B		✔		
SM-2 standard missile		✔		
T-AGOS ocean surveillance ship		✔		
T-45		✔		
Trident II missile				
AIM-7M			✔	
AIM-54C			✔	
CG-47 class			✔	
E-6A			✔	
F-14D			✔	
LCAC-1 class			✔	
T-AO-187 class			✔	
UHF follow-on			✔	
A-6E/F				✔
AV-8B				✔
AGM-88				✔
RIM-7M				✔
AIM-9M				✔
AN/BSY-1-2				✔
AN/SQQ89				✔
AOE-6 class				✔
UGM-109				✔

Table 4.2—continued

System	Rejected at Criterion I: Still in EMD	Rejected at Criterion I: Funding Programmed Beyond FY95	Rejected at Criterion II	Possible Candidates for Restart
E-2C				✔
FFG-7 class				✔
LHD-1 class				✔
MCM-1 class				✔
LSD-41 class				✔
MHC-51 class				✔
S-3A/B				✔
UGM-84				✔
C/MH-53E				✔

types might be needed in the future, and at this time no direct equivalents are available. However, if funding for those systems is severely curtailed, maintaining adequate shipyard facilities might become critical. These issues are highly specialized and beyond the scope of this exploratory study; consequently, we have set aside three current ship classes (SSN-21, CVN-72, and Ohio-class submarines) as "special situations" and have made no attempt to assess the likelihood of needing additional quantities of such ships in the future.

The screening process indicates that it might be desirable to restart production of six types of naval vessels, five aircraft, five missiles, and two electronic systems, all of which are currently operational and have production lines that have been recently closed or that are scheduled to close in the next few years.[4] Major considerations in the Navy screening are as follows:

- A-6E Intruder attack aircraft
  - Last new production aircraft delivered to Navy in late 1991
  - Only Navy/Marine night and all-weather attack aircraft
  - Inventory is short of requirements for Base Force

[4]Submarines are a special case and are not included here. A report discussing submarines separately is in preparation.

- Potential for high attrition
- Follow-on AX will not reach IOC until at least 2005.

• AV-8B Harrier II
- Potential for high attrition (peacetime and combat)
- Few or no alternatives
- Ideal for LIC environment
- High potential for FMS.

• AGM-88 HARM
- Potential for very high consumption rates
- Proven system with few alternatives that are as effective.

• RIM-7M Sparrow
- Potential for high consumption rates
- RIM-7 is Navy shipboard BPDMS; few or no suitable alternatives exist.

• AIM-9M Sidewinder air-to-air missile
- Potential for high consumption rates
- Proven, highly effective, short range, infrared missile
- No substitute available in near future.

• AN/BSY-1-2
- Combat system for SSN-21 and Centurion
- Low demand; primarily electronics and software
- Resurgent ASW emphasis might require additional systems.

• AN/SQQ-89
- State-of-the-art ASW suite for surface combatants
- Low demand; primarily electronics and software
- Might be used in outfitting new ships or upgrading ships brought out of storage to meet resurgent threat.

- AOE fast combat support ship
  - — AOE-6, last ship of class, was funded in FY92
  - — Conversion of existing ships to support ship function would be difficult or costly
  - — Combat Logistics Force (CLF) is being sized to combatant fleet, but future contingencies could require larger force
  - — Four- to five-year lead time to delivery, when in production.
- A/R/UGM-84 Harpoon cruise missile
  - — Potential for high consumption rates
  - — Last procurement was appropriated in FY91; Congress added funds
  - — SLAM version could increase demand.
- C/MH-53E Stallion helicopter
  - — Primary heavy-lift assault platform for USMC
  - — Follow-on is not in development
  - — Potential for high attrition
  - — Excellent LIC weapon system.
- E-2C Hawkeye
  - — No or few alternatives without antenna technology breakthrough
  - — Follow-on is not in development
  - — A few excess systems available[?].
- FFG-7 Oliver Hazard Perry–class frigate
  - — Frigates constitute the lower-cost and lower-capability end of warship spectrum
  - — 51 ships in class; last ship commissioned in 1988
  - — Potential alternative to DDGX (Burke follow-on).

- LHD-1 Wasp-class amphibious assault ship
  - Ideal LIC and presence weapon system.
- LSD-41 Whidbey Island–class dock landing ships
  - Ideal LIC and presence weapon system.
- MCM-1 Avenger-class mine countermeasures ships
  - Potential for high attrition
  - Increasing use of mines worldwide for combat and terrorism
  - Small force size of only 14 ships.
- MHC-51 Osprey-class coastal mine hunter
  - Potential for high attrition
  - Planned force size is small.
- R/UGM-109 Tomahawk
  - Potential for high consumption
  - Potential for continuing P^3I to meet changing threat
  - Ideal for use when loss of U.S. personnel is not permissible.
- S-3A/B Viking
  - Primary mission was ASW; potential strong contributor to ASUW, EW, and carrier air wing tanking missions
  - Has been proposed for production restart several times
  - Airframe could be used in many mission areas.

Air Force Systems

Table 4.3 summarizes the preliminary assessment of Air Force systems. Of the 35 systems that are covered by SARs and that are reasonably modern, six are still in EMD and another seven currently have procurement funding programmed for years beyond 1995. Of the remaining 22 systems, only 11 were deemed to be possible candidates.

Table 4.3

Summary Assessment of Air Force Systems

System	Rejected at Criterion I: Still in EMD	Rejected at Criterion I: Funding Programmed Beyond FY95	Rejected at Criterion II	Possible Candidates for Restart
ATARS	✓			
E-3A AWACS RSIP	✓			
C-17A	✓			
F-22	✓			
JSTARS-radar	✓			
JTIDS	✓			
AMRAAM		✓		
DSP		✓		
GPS satellite		✓		
GPS user equipment		✓		
CBU-97/B		✓		
Titan IV ELV		✓		
C-130		✓		
AIM-7M			✓	
AIM-9M			✓	
ALCM			✓	
CSRL			✓	
DMSP			✓	
DSCS-III			✓	
E-3A AWACS			✓	
F-15			✓	
GLCM			✓	
KC-10A			✓	
LGM-118 Peacekeeper			✓	
A-10				✓
AGM-65 Maverick				✓
AGM-88 HARM				✓
AGM-129 advanced cruise missile				✓
B-1B				✓
B-2				✓
C-5B				✓
F-16				✓
F-117				✓
IUS				✓
LANTIRN				✓

Two systems were particularly difficult to classify because of the uncertainty over the status of follow-on systems. The C-5B fleet will presumably be augmented by the more modern C-17. However, the C-17 has yet to be proven, and it appears to be substantially more expensive than the C-5B. Until these issues are clarified, rejection of possible C-5B restart appears to be premature. Likewise, the F-16 is scheduled to be replaced by the proposed Multi-Role Fighter (MRF). However, the status of that system is uncertain, and the F-16 might be kept in production until plans for a follow-on become more certain. If the F-16 production line should be closed before the status of the MRF is clarified, then provisions should be made for efficient restart. Meanwhile, both the C-5B and the F-16 are listed as likely candidates for production restart.

The future of U.S. strategic missile forces and of a range of space assets are also hard to foresee at the present time. However, all of those systems appear robust in the face of current threats, and if there is much delay in need for additional quantities, it seems likely that newer systems would be substituted. Therefore, those systems are classified as being unlikely to justify production restart in the near future.

Major considerations in the Air Force screening are shown below.

- A-10
  - Potential for combat attrition
  - Possible demand for LIC
  - No close substitute or follow-on.
- AGM-65 Maverick
  - Demand possible via consumption
  - Modern, effective weapon
  - No substitute available or planned.
- AGM-88 HARM
  - Possible high consumption rate
  - No substitute available or planned.

- AGM-129 advanced cruise missile
  - — Possible demand via combat consumption
  - — No close substitute or follow-on
  - — Most modern example; no close alternative
  - — Could be equipped with nonnuclear warhead, used in regional conflicts.
- B-1B
  - — Demand possible for force expansion or to replace combat loss
  - — No close substitutes available or planned.
- B-2
  - — Demand possible for force expansion
  - — Unique capability; no ready substitute.
- C-5B
  - — Demand possible for force expansion
  - — Newer C-17 might serve as substitute.
- F-16
  - — Demand possible via combat attrition
  - — No close substitute now available
  - — Large quantities available, some in storage
  - — Further production might be scheduled to permit delay in introducing MRF
  - — Eventual replacement by MRF.
- F-117
  - — Demand possible via combat loss or force expansion
  - — Most modern example; planned replacement not yet started.

- Intermediate Upper Stage
  - Consumed in use
  - Likely demand for future space launches
  - No substitute available or planned.
- LANTIRN
  - Demand possible via combat consumption or force expansion
  - No substitutes available.

SUMMARY AND CONCLUSIONS OF INITIAL SCREENING

This initial screening of candidate systems addressed only issues dealing with whether a production restart might be deemed a *desirable* option, in the event that currently programmed forces need to be augmented.

The screening examined a broad range of weapon systems that have not been canceled or clearly superseded by other designs. In total, 115 such systems were identified and reviewed. The results of the review are summarized in Table 4.4.

Of the 115 systems, nearly half are either still in EMD or are currently in production and are programmed for procurement beyond 1995. Those systems were excluded from further consideration because no

Table 4.4

Summary Results of Production-Restart Analysis

Assessment	Number of Systems	Percentage of Total (%)
System now in EMD, or procurement is programmed for years beyond 1995	56	49
Need for additional quantities deemed unlikely	7	6
Additional quantities might be needed, but other options are deemed better than production restart	17	15
Production restart is a reasonable tactic	35	30
TOTAL	115	100

decisions related to production restart seem warranted in the immediate future. Those systems should be examined when they near the end of their programmed procurement, whenever that occurs.

Of the remaining systems that were subject to detailed examination, seven were eliminated because it appeared that present or programmed quantities were adequate to satisfy needs over a wide range of future contingencies. For example, a space-based communications system sized for major war contingencies is unlikely to need reconstitution under any plausible range of future contingencies.

For 17 of the systems examined, additional quantities of like systems might be needed for reconstitution, but those needs were deemed capable of being satisfied by drawing from excess stocks or from production of follow-on or alternative designs. For example, if the Air Force needs additional tanker aircraft to replace or augment the KC-10A, those would almost certainly be obtained by creating a tanker version of a modern transport aircraft already in production.

After screening out the systems considered not to be candidates for possible future restart, 35 remain—just under one-third of the original list; 13 are flight vehicles of one kind or another, 7 are ships, and 11 are missiles. The industrial base for aircraft is sufficiently large to ensure the feasibility of production restart. The industrial base for production of large naval vessels appears more uncertain in the face of continuing budget reductions. In each individual case, however, questions of overall feasibility, practicality, cost, and schedule would need further investigation.

Questions of the *practicality* of such restart must be examined on a case-by-case basis and were beyond the scope of the present study. Alternative reconstitution strategies are described in the following chapter.

Chapter Five

ALTERNATIVE RECONSTITUTION STRATEGIES

This report examines production restart.[1] That notion, however, is only one of several possible strategies for strengthening the United States' ability to renew or expand elements of its military force. Part of our research task was to identify (but not study) other options that might be employed in certain circumstances. Here we describe two additional broad options that might be applied to either current or future weapon systems:

- Maintaining production at a very low rate, possibly deferring satisfaction of immediate needs in return for sustaining an active production line over a longer period of time
- Producing at an efficient rate, beyond satisfaction of immediate needs, with the excess stored for use in future contingencies.

Each strategy involves a different balance between near-term costs (which might be one-time or recurring), and the time and cost required for producing additional quantities of an item in the future. Significant differences are expected between programs in which weapon systems are already in production and new developments in which manufacturing decisions could be based on one of the above production options. Table 5.1 summarizes the two production op-

[1]There is a tendency to think of "reconstitution" as producing more of an "old" (and therefore low-capability) system. But that is just one end of a broad spectrum. On the other end is a model change with greatly increased capability and significant savings over an "all new" system.

Table 5.1

Production Options

Category	Existing Systems	New Systems
Restart production	Stop production when program need satisfied. Perform "smart" shutdown. Restart production in future if needed.	Develop and test new system, produce only enough to prove production process. Preserve low-rate capability. Restart production, expand rate as needed in future.
Sustained low-rate production	Continue production at low rate to maintain active production capability, permitting rapid surge to higher rate if needed.	Establish initial production line for efficient operation at low-rate.
High-rate production with storage	Extend normal production; store excess items until needed.	After normal production run, produce at efficient (high) rate to cover future requirements; store quantities in excess of present requirement until needed.

tions above plus the restart option for both current and new systems. In addition we consider a special variant of production restart: sustaining a "warm" production line.

SUSTAINING A "WARM" PRODUCTION LINE

When production of a particular system has been completed, the typical action is to disband the production staff and dispose of the production facilities, either by storing, scrapping, or reassigning them to some other program. Past experience shows a high degree of variation in the extent to which staff is scattered and facilities are disposed of. The cost and time incurred in reassembling or re-creating a production capability will depend on the nature of the shutdown.

For certain kinds of weapon systems, the cost and time to re-create a production capability may be great, especially where the industrial capacity for critical components is very low and where no commercial demand exists for related production technologies or facilities. Under those circumstances, completely terminating production may mean that it could take a very long time and much money to recreate the requisite capabilities. Such cases may benefit from sustaining some level of production capability to ensure timely restart if and when it becomes necessary. This practice is typically referred to as maintaining a "warm" production line.

We define a *warm production line* as a production line retained in its complete configuration with all tooling, machines, and other equipment remaining in place in the original factory but without production work being performed. The same kind of retention would be needed at all critical suppliers, that is, all suppliers who did not have other production lines that could be immediately switched to the fabrication and assembly of the subject-system components. No production or production support staff would be retained—only a caretaker staff to ensure that the tools and equipment remain in serviceable condition.

An inactive line suffers two kinds of cost: the recurring "rent" on the tools and facilities and the cost of training a production staff if restart is needed. The time required to restart production would be defined by the order time for the longest-lead-time parts and supplies, together with the normal industrial flow time of fabrication and final assembly, and by the training and staffing time required to create a qualified workforce. This strategy might be appropriate in some cases.

SUSTAINING LOW-RATE PRODUCTION

The notion of sustaining a low production rate is usually introduced in the context of a system that has already been produced in some significant quantity.[2] Sustaining a low rate of production for these systems is often quite costly, since facilities, plant layout, and initial investment were planned for economic (higher) production rates. This alternative maintains both human skills and productive capacity.

This approach is sometimes advocated when the system is critical to national defense, there is only one qualified supplier for critical parts of the system, and those parts have no commercial market. In such a case the suppliers might go out of business if the production line is closed.

The dollar cost of sustaining an active production line can be high, presuming there is essentially no current demand for the products. Preliminary calculations suggest that if the expected gap in production is likely to be two years or longer, it is economically advantageous to completely close the facility and put it into inactive status (providing, of course, full and complete preparations for restart are funded and accomplished and a small sustaining team is put in place). For example, it has been estimated that if the production facilities (final assembly and major suppliers) for the M-1 tank were closed and put into long-term inactive status, it would cost roughly $1 billion to bring those facilities back to high-rate production. The lowest production rate that might be sustained in order to keep the line open has been suggested to be about ten units per month. At a $5 million unit cost, 20 months of production would equal the cost of refurbishing the original production capability.

[2]For new systems, initial low-rate manufacturing is sometimes referred to as *pilot production.*

We found one example of a commercial aircraft production line for which it was economical to completely shut down the line while retaining tools and facilities in place, even though the expected downtime was one year. Some very rough calculations for other kinds of systems indicate that the economic break-even point is typically in the range of one to two years, assuming that the facilities have been preserved in a reasonable condition.

However, an active production line might, in certain cases, significantly reduce the time required for renewing production at higher rates to satisfy a Force Reconstitution demand.[3] For example, consider the case of very specialized items, such as critical parts of a ship propulsion reactor. If production had been completely stopped and all staff disbanded, it could easily be expected to take several years to assemble, train, and qualify a production and management staff capable of producing the items to the requisite quality standards. Add that to the normal assembly time of roughly five years required for major combat ships, and it can be envisioned that a total time of ten years or more might be needed for first-item delivery. If that lead time is deemed unacceptably long, the high recurring cost of sustaining a low production rate might be justified.

A special variant of this general option is the case where a new system has been developed and brought to production status, but quantity production is deferred pending clarification of operational need. To achieve high confidence in producibility and to demonstrate operational effectiveness, it might be necessary to produce a modest quantity of the full-production configuration.

There are few, if any, historical examples of such a policy being implemented for new systems. Furthermore, the whole notion of spending funds necessary for full development but then not exploiting that investment through high-rate production for inventory is directly contrary to current acquisition policy. However, for the environment envisioned for the 1990s, such a practice appears to have at least two attractive qualities, providing that development is completed and at least a small number of operational systems are put into service evaluation. First, it is a method of hedging against an

[3]Each particular case determines the extent to which low-rate production can be rapidly and easily scaled up.

uncertain range of future threats. By developing some specialized systems but deferring the cost of quantity production and recurring operations, it would be possible to create a broader range of potential combat capabilities. Second, the process should make a major contribution to sustaining and strengthening the industry infrastructure needed to design and develop advanced-technology weapon systems.

The V-22 aircraft might be considered a candidate for such an option. The system is now nearing the end of its development phase, and funding has been provided for production of a few vehicles, sufficient for development of employment tactics and realistic demonstration of field capabilities. Furthermore, the system has unique capabilities that could, under some circumstances, greatly increase force capability. However, additional funding for quantity production is subject to considerable controversy. It might be appropriate to maintain production facilities in "inactive" status or produce at very low rates until more experience is gained with the aircraft and until the benefits of its particular capabilities become more clear.

MAINTAINING HIGH-RATE PRODUCTION WITH STORAGE

High-rate (efficient) production beyond satisfaction of immediate needs with the excess stored for use in future contingencies is another option. For existing systems, such as the B-2, an excess number of airframes could be produced and flight-tested. A set of engines and avionics could be installed, used to test the airframe, then removed and reused to test the next production airframe. Airframes not needed would be stored until needed. DoD would be spared the costs of acquiring all the engines and avionics, and would have the airframes, which are the long-lead, most costly, and most technically difficult element to reconstitute.

This option permits DoD to exploit the inherent learning and fixed-cost economics available in a specific production process without incurring the full cost of the system. This option is particularly attractive (1) the more the component contributes to a system's overall lead time, (2) the more difficult the component is to produce, and (3) the lower the portion of the component's cost is relative to that of the end item.

The drawbacks to this approach are the costs incurred to produce and store airframes for which no operational needs now exist, and that it does not involve regaining capacity.

SUMMARY

Before any conclusions can be drawn about the merits of these alternatives relative to each other or to restart, each would have to be examined for a range of weapon system types and a range of scenarios. The major variables for system types are

1. The lead time required to restart or accelerate production
2. The cost of either
   a. Maintaining inactive production capacity, then bringing it up to active status or
   b. Creating a new production capacity
3. The cost for sustaining production at some minimum rate
4. The cost, time, and service-life implications of storing completed systems, then bringing those systems to operational status.

The major scenario variables are

1. The strategic warning time presumed to be available in which to decide that additional quantities are needed
2. The rate of desired buildup in production rate and completed systems.

Chapter Six

CONCLUSIONS

As the United tates enters a period of national history in which defense budgets become more limited and future international relations are clouded or uncertain, defense planning aims to achieve a balance between cost and risk. This is particularly true with regard to the issue of force levels and reconstitution policies: For both new and existing weapon systems, acquisition quantities and acquisition policy options that have never or rarely received serious attention become key issues. Closing a production line while preserving the option to reopen it at a later time is one of several policies under consideration. This report addresses cost and schedule comparisons relative to new programs, measures to ameliorate the problems of restart, criteria for selecting restart candidates, and alternative reconstitution strategies. Our findings are summarized below.

WHAT DOES EXPERIENCE SHOW REGARDING THE SCHEDULE AND COST OF RESTART COMPARED WITH THOSE OF ORIGINAL PRODUCTION?

There are many major systems for which production has been stopped, then restarted sometime later. Aircraft, in particular, have experienced breaks in production ranging from a year to a couple of decades. The extreme case seems to be ships, on which production is passed from one yard to another, and, even at one shipyard, other models are sometimes interspersed in the production sequence. The notion of serial production seems rarely to apply to ships.

Restarting a production line for such systems as aircraft and missiles can be relatively uncomplicated provided that (1) the original manufacturer is still in business, (2) critical information, such as manufacturing process standards and key supplier list is available, and (3) major fabrication and assembly jigs and fixtures still exist. (The original assembly plant is not necessary, because the tools and other equipment needed to manufacture an aircraft or missile can be, and often have been, moved to some other facility.) Although items included in (1) and (2) could, in principle, be regenerated, we have no data on the time and cost of restarting "from scratch."

With regard to schedule, we found that, measured in the time required to deliver a production aircraft, restart is typically faster by one or two years than producing the original system. However, current acquisition practices include a demonstration and validation phase, prototypes, and extensive risk-reduction activities, which cumulatively could stretch an all-new acquisition program up to ten years in today's environment. In a restart program, on the other hand, an entire support network is in place—maintenance personnel, spares, manuals, special test equipment, etc. Compared on the basis of time to achieve equal operational readiness, a restart program offers an advantage of many years. Furthermore, restarting production of an item that has previously been in service presents a very low risk compared with developing a new item.

The cost data collected enabled us to compare nonrecurring and recurring labor costs—engineering, tooling, manufacturing, quality assurance, and total—of the restarted program to original costs. For nonrecurring costs, a detailed breakdown exists for only two programs: the C-5 and S-3. Total nonrecurring restart man-hours are about 10 percent those of the original program; engineering is less than 10 percent; and the other labor elements are in the 10- to 20-percent range.[1] While there are too few data points to support a systematic method for predicting nonrecurring restart costs, the numbers should be helpful in making estimates by analogy.

Our recurring-cost data indicate overwhelmingly that restarts begin at lower first-unit values and proceed on shallower slopes than their

[1]The major activity in restarting a production line that has been shut down and the tooling moved to storage is to reestablish the tooling and work flow, including inspection and test. Consequently, it is not surprising that tooling and quality assurance have the highest percentage restart costs.

corresponding original programs. On the average, recurring production and quality-assurance labor restart at approximately 50 percent of the original first-unit cost, and engineering and tooling restart at approximately 20 and 40 percent, respectively. The restart percentages for total labor are smaller and depend on the extent of nonrecurring activities included in both programs. Excluding the B-1, which did not achieve full-production capability in the original program, 37 comparisons of original and restart learning curves *all* have restart first-unit costs lower than the original and restart slopes shallower than the original. In addition, of ten restart cases for which only a single data point is available instead of full curves, nine have points below the original learning curves and the tenth is on the original curve.[2]

Regression analyses were performed to determine which program characteristics have the most influence on restart first-unit cost and slopes. For recurring costs, the only significant determinants of restart first-unit cost were the original first-unit cost and the original slope. For the total and combined-sample cases, the length of the production gap also entered as a significant explanatory variable. This difference suggests that the length of the production gap has little to do with recurring costs as production resumes but does influence nonrecurring costs. For the restart-slope regressions, the original slope and the ratio of restart to original first-unit costs were the only significant variables.

The data and analyses presented here give a clear and consistent indication that restarting aircraft programs that have previously achieved full-production capability and have then been shut down should result in follow-on programs that require less time from program start to first delivery and are significantly less expensive and of much lower risk than the original programs.

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[2]Sample sizes are small, however, when the 37 cases are sorted out into the four labor categories and between total- and recurring-cost curves. The largest samples have ten observations (recurring production), and the smallest have only three (recurring engineering and tooling). Even though the sample sizes are small at the individual labor-component level, the results are consistent with experience.

WHAT ACTIONS SHOULD BE TAKEN AT SHUTDOWN TO FACILITATE EFFICIENT RESTART?

By taking certain actions at the time a production line is closed, the time, cost, and uncertainties associated with restarting it can be significantly reduced. When a decision has been made for a particular system that the production-restart options will be adopted, the following policies are recommended.

The government program office, as part of its last contract, should fund and work with the contractors to develop a shutdown plan that preserves those documents, tools, etc., that are needed to restart production. As part of this process, videotapes and photographs of fabrication and assembly activities should be made, not only so that a record is available on how the system was produced but to serve as training aids for follow-on workers. Interviews with key shop and technical personnel should be part of this documentation. This activity need not be expensive. Indeed, it can cost less than routine disposal of the tools in accordance with government regulations.

While we caution DoD to strive to keep costs down, the potential cost and time savings are so significant that DoD should invest in those systems it determines to have a high probability of restart. Although the investment in preserving the production-restart option is system-specific, our research shows costs associated with a "smart shutdown" are an insignificant fraction of the resources required to replace just original tooling.

In addition, for those systems identified as candidates for production restart, consideration should be given to having the contractor serve as the overhaul facility so that engineering, production and management skills, and facilities remain active and intact. The dollar benefits are difficult to quantify; however, several programs that were reconstituted clearly would have required more time and money if the prime contractor had not acted as the depot and maintained configuration control.

HOW SHOULD RESTART CANDIDATES BE SELECTED?

An important task of this research has been to develop a method to determine which systems should be considered as possible candidates for restarting production. We have devised and applied a screening framework from which have emerged a set of candidates to illustrate that a logic-driven screening process can be constructed and used to select plausible restart candidates.

Developing a universal methodology is difficult and probably not practical. Therefore, we suggest that senior decisionmakers should add or subtract criteria according to the system being considered. Our initial screening addressed only issues dealing with whether a production restart might be deemed a *desirable* option, and represents only a *coarse* screening of candidate systems. *We are not recommending that DoD make the investment to preserve the option to reconstitute these candidate systems; rather, our purpose has been to illustrate that the investment, if made, needs to be for only a few systems.*

This review examined a broad range of weapon systems that have not been canceled or clearly superseded by other designs. A total of 115 such systems were identified and reviewed. The results of the review are summarized in Table 6.1.

Of the 115 systems, nearly half are either still in EMD or are currently in production and are programmed for procurement beyond 1995. Those systems were excluded from further consideration because no decisions related to production restart seem warranted in the im-

Table 6.1

Summary Results of Production-Restart Analysis

Assessment	Number of Systems	Percentage of Total (%)
System now in EMD or procurement is programmed for years beyond 1995	56	49
Need for additional quantities deemed unlikely	7	6
Additional quantities might be needed, but other options are deemed better than production restart	17	15
Production restart is a reasonable tactic	35	30
TOTAL	115	100

mediate future. Those systems should be examined when they near the end of their programmed procurement, whenever that occurs.

After screening out the systems considered not to be candidates for possible future restart, 35 remain—just under one-third of the original list; 13 are flight vehicles, 7 are ships, and 11 are missiles. The industrial base for aircraft is sufficiently large to ensure the feasibility of production restart. The industrial base for production of large Navy vessels appears subject to greater uncertainty in the face of continuing budget reductions. For each individual case, however, questions of overall feasibility, practicality, cost, and schedule would need further investigation.

It is worth noting, however, that one issue of practicality *can* be assessed: Is the system currently operational? This question is important for at least two reasons. First, if a system is operational and if the system is a vehicle or other item that requires maintenance, repair, and overhaul, then many of the industrial suppliers necessary to support production are still in business, supplying spare parts and maintenance services to the system. This being true, restarting a production line becomes a much more realistic and practical matter than if all, or most, of the original suppliers have quit building the kind of items needed. Second, the existence of an operational cadre, plus the supporting infrastructure within the service as well as within industry, means that introduction of additional units into the inventory should go much more easily than if the system is completely out of operation. This practicality criterion should be included in the screening process.

WHAT ALTERNATIVES TO PRODUCTION RESTART MIGHT BE USEFUL?

Reconstitution is only one of several possible strategies for strengthening the United States' ability to renew or expand certain elements of its military force. Two additional options that might be applied to either current or future weapon systems are

- Maintaining production at a very low rate, possibly deferring satisfaction of immediate needs in return for sustaining an active production line over a longer period of time

- Producing at a high (efficient) rate beyond immediate needs, with the excess stored for use in future contingencies.

Each strategy involves a different balance between near-term costs (which might be one-time or recurring), and the time and cost required for producing additional quantities of an item in the future. No rigorous research has been performed on cost and schedule attributes of these options. Each should be the subject of additional research. Once each option is understood, it could then be examined across weapon-system types and a range of scenarios. Possible major scenario variables are

1. The strategic warning time presumed to be available in which to decide what additional quantities are needed
2. The rate of desired buildup in production rate.

Appendix A

ARMY MUNITIONS STARTUP PROBLEMS

In the course of our research we asked ammunition plant representatives and production managers to identify problems encountered when munitions production has stopped and is subsequently restarted months or years later by the government or private contractors. Stopping and restarting small munitions production is a fairly common practice. A summary of the most common problems is as follows:[1]

1. Locating personnel who have expertise in running a particular line is often difficult. A prime example is the 16"/50 Cal projectile, which was last produced in the 1950s. No one was available who had ever run the line. Sufficient documentation is the key to maintaining expertise. McAlester Army Ammunition Plant is considering using videos to aid in future training.

2. The need to rehire personnel or shift them from other lines often requires obtaining security clearances and providing intensive training. The learning period then becomes longer for startup in direct proportion to the number of new people involved.

3. Safety regulations change, which may require a larger safe-separation distance for the line. This requirement may entail moving the entire line to new facilities. Stricter adherence to Environmental Protection Agency and safety regulations may

[1]Department of the Army, Headquarters, U.S. Army Armament, Munitions and Chemical Command, Rock Island, Illinois, letter dated February 28, 1992.

necessitate different machines, procedures, and quality-control checks.

4. Technological changes may cause delays: The more mechanical, labor-intensive procedures used in the past have been replaced by numerical-control machines, robotics, or other time- and labor-saving devices. These changes require new programming and training.

5. Even when preventive maintenance is performed, machinery still has a tendency to break down when it is not used for a long period of time. Additional time is required to repair or refurbish machines and equipment that have been laid away.

6. Technical data may be out of date, and specifications may also require updating. If changes in the original production were accomplished by deviation and waiver, rather than by Engineering Change Proposals, they may not have been recorded. Requalification of the entire process, including personnel, production equipment, test equipment, and component parts. is required. Many ammunition items require 100 percent radiographic inspection to requalify.

7. Materials suppliers may no longer be in business. Locating qualified suppliers often causes delays. It may also cause problems with "just in time" procurements.

9. Technological improvements in packaging may require updating machines or facilities for loading and packing. Lines that were originally set up for certain procedures may now be out of date.

10. The ability to detect production problems and correct them is improved the longer a line runs. Starting and stopping production lines for even short periods is not cost-efficient.

Appendix B

PRODUCTION RESTART OF NAVAL SHIPS

Large Navy ships, especially combatants, present production-restart issues that are different from those for most other types of weapon systems. Although a detailed examination of these issues was beyond the scope of the present study, we present here a brief outline of some special considerations.

Major naval vessels are different from other systems in at least three ways that affect planning for possible production restart. First, ships are typically ordered and built one at a time, with the same design sometimes being produced by different yards. It is, in fact, common practice to split the production of a single design between two yards. Thus, as long as an adequate facility exists, many Navy ships can be "reordered" at almost any time, assuming that the original design data have been preserved and that the necessary equipment is available, or an adequate substitute is available.

Second, ships are unique in terms of facility requirements. A shipyard represents a major installation, and one not easily duplicated. Furthermore, the number of active and capable yards is limited. Even with no further contraction of the shipbuilding industry, the maximum production rate of certain kinds of ships (particularly nuclear-powered ships) is quite limited. Thus, the constraint on ship "production restart" seems to be focused on the facilities and on the associated staffs of trained personnel. If those two resources are available, additional construction of ships previously built appears to be a common activity.

Third, ships are special in terms of the lead time required to go from a new production order to a fully operational system. Typical ships require something like four to five years to launch and another year to reach full operational status. Even longer times are required for very large ships, such as aircraft carriers. For this reason, it is harder to wait until the last minute and then order a batch to satisfy a new need.

One consequence of the shipyard constraint, plus the long lead time, is that ships are limited to relatively low total national production capacity, as the historical data presented in Table B.1 illustrate. The six most-productive yards (in terms of ships produced per decade) have cumulatively produced an increasing fraction of the total number of Navy ships procured. Those six yards produced half the ships commissioned in the 1960s, about 70 percent of the ships commissioned in the 1970s and 1980s, and will deliver about 90 percent of the ships to be commissioned in the first half of the 1990s.

Table B.1

Naval Ship-Building Rate, All Ships over 1,000 tons

	Ships Commissioned per Decade				
Shipyard	1960s	1970s	1980s	1990–1994	1960–1994
Avondale	9	27	12	16	64
Percentage of Navy total	4	16	8	21	10
Bath Iron Works	16	7	25	10	58
Percentage of Navy total	8	4	16	13	9
GD/Electric Boat	26	13	31	14	84
Percentage of Navy total	13	8	20	18	14
Ingalls	13	42	24	13	92
Percentage of Navy total	6	24	15	17	15
NASCO	7	18	4	3	32
Percentage of Navy total	3	10	3	4	5
Newport News	30	17	16	13	76
Percentage of Navy total	15	10	10	17	12
Total of six yards	101	124	112	69	406
Percentage of Navy total	49	72	71	90	66
All Navy	205	172	157	77	611

Of those six most-productive yards, only four (Bath, General Dynamics [GD]/Electric Boat, Ingalls, and Newport News) have produced combatants, with modern electronics and armaments, in the past decade or so. Furthermore, only two of those yards are nuclear-capable, and those same two are currently the only builders of submarines (see Table B.2).

At least a dozen other shipyards are active in this country and capable of building a wide variety of ships; at least some of those yards could, over time, expand their staff and facilities to permit construction of combatants. How long such expansion might take is speculative, but it would almost certainly be measured in years, especially if the present yards were busy and no surplus of experienced people was available.

The current Navy has roughly 500 ships, comprising combatants and major support ships. The evolution of fleet size is shown in Table B.3. For a 300-ship navy with an average retirement age of 30 years, rate of commissioning is just barely keeping pace. So, for the United States to increase its naval power by some significant fraction (say, 50 percent) would take at least one decade, even if retiring of ships stopped.

The combination of low rate and long lead time makes a naval fleet a thing that is modified only very slowly. Since national needs can

Table B.2

Ships Commissioned per Decade

Shipyard	1960s	1970s	1980s	1990–1994	1960–1994
Electric Boat	26	13	31	14	84
Percentage of Navy total	33	43	72	56	48
Ingalls	7	4	0	0	11
Percentage of Navy total	9	13	0	0	6
Newport News	22	8	12	11	53
Percentage of Navy total	28	27	28	44	30
Total of three yards	55	25	43	25	148
Percentage of Navy total	71	83	100	100	84
All Navy	78	30	43	25	176

Table B.3

Fleet Evolution

	1960		1970		1980		1990
Inventory	1,100						
Gains		200					
Losses		(600)					
Inventory			640				
Gains				170			
Losses				(330)			
Inventory					480		
Gains						150	
Losses						(120)	
Inventory							510

change in less than a decade, the United States might need to sustain something more than a bare minimum force and some active industrial capacity in order to shorten the response time. One question is, How much can the country afford? (Remember, we have said elsewhere that maintaining production of something you do not need can be terribly expensive.) Another question is, What is a strategy for sustaining some of the desired posture at a minimum cost?

Appendix C

HISTORICAL RESTART COST-ESTIMATING METHODS

Cost is a basic concern in any consideration of production restart, and methods of estimating that cost are essential. It is important to remember, however, that production breaks are not new, and they are not confined to the aerospace industry. They are common in companies manufacturing a variety of products, and their effect has been the subject of a number of studies. Most early studies were limited to their effect on direct manufacturing hours and to interruptions of a few months. Without exception, such studies were based on learning-curve theory, i.e., that the labor content in a product decreases as production quantity increases. Those studies found that labor hours regressed to some earlier point on the learning curve after an interruption. Usually, the loss of learning was associated with the length of the break.

DOUGLAS AIRCRAFT COMPANY

The Douglas Aircraft Company observed that regression effect as early as 1938 in a production gap on the TBD-1 and has collected data on a number of items manufactured since then that substantiate the early findings. When bidding future production, Douglas has used the method to estimate direct manufacturing labor hours, with an anticipated interruption both at the shop-order level and for total airframes.

ASD MODEL

The Aeronautical Systems Division (ASD) model, developed at Wright-Patterson AFB in 1957, is typical of early models. As depicted in Figure C.1, loss of learning is a function of the months of interruption. A six-month break results in a loss of 40 percent of the units previously produced. That is, if 100 units had been produced before the break, the 101st unit would have a value equal to that of the 60th unit. After a 48-month break the ASD model assumes that all learning is lost, i.e., that the expected first-unit cost of new production would be the same as the original first-unit cost.

AVSCOM MODEL

The U.S. Army Aviation Systems Command (AVSCOM) took an entirely different approach when estimating the cost of a proposed buy of 200 new AH-1G helicopters in 1973 after at least a two-year break. Five lots had been produced previously: three lots (838 units) without interruption, then, after a 13-month break, two additional lots (244 units). The average cost of the latter two lots was 23.9 percent higher than it would have been had production been continuous, i.e., had the slope of the original learning curve been maintained. The Army Aviation Command assumed the cost of an interruption to be 23.9 percent and used that factor in estimating the cost of the next lot. The difference in the length of the two breaks was not considered important.

DCAA MODEL

Most Department of Defense organizations, however, have tended to relate loss of learning to time. The Defense Contract Audit Agency (DCAA) argued, back in the 1970s, that while loss of learning is related to the length of a production break, it is not a linear function of the time involved.[1] DCAA cites a case in which a contractor claimed, based on experience building cargo ships and LSDs, that interruptions in production resulted in a cost increase per month of

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[1] Defense Contract Audit Agency, *Application of BREAK Program, 1976 Advanced Audit Techniques Seminar Pamphlet*, Memphis, Tenn.: Defense Contract Audit Agency, September 1976.

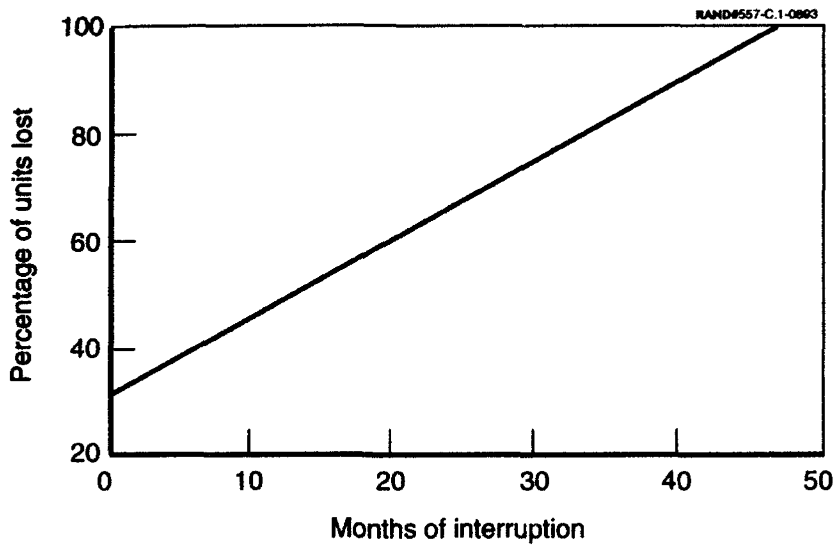

Figure C.1—ASD Model of Learning Loss

0.437 percent for cargo ships and 0.453 percent for LSDs, or an average increase per month of 0.445 percent. Using a DCAA program called BREAK, the auditors showed that when loss of learning is measured in terms of production units, the percentage loss of learning was greater for the 14-month interval between LSD deliveries than for the 22-month interval between cargo-ship deliveries. They concluded that, in the shipbuilding industry, the bulk of that learning which is going to be lost is lost in the first 14 months. Most of the learning, however, will never be lost because it lies in documents "related to problems encountered in the construction of previous ships and the proper scheduling and layout of the work."

Aircraft manufacturers, such as Lockheed and Boeing, agree with that statement. Lockheed's experience has been that, as long as tooling concepts do not change, loss of learning does not reach 100 percent even after a 10-year gap. They maintain that the relationship between production-break length and loss of learning is affected by a variety of factors—planning, availability of facilities and personnel, condition of tooling, etc.—all of which should be taken into account when estimating the overall effect of an interruption in production.

ANDERLOHR MODEL

The Anderlohr model provides a good example of how those factors can be taken into account. That model was developed for use in cost negotiations when a method for estimating loss of learning was needed that would be acceptable to both the government and contractors. The model assumes that loss of learning is due to changes in five factors: production personnel learning, supervisory personnel, continuity of production, special tooling, and methods.[2] Each of the five factors must be assigned a weight appropriate to the product or the company. Anderlohr uses a default value of 20 percent for each in the example in his article.

The example shows the kind of assumptions that must be made for each of the factors. For production personnel learning and supervisory learning, for example, it is estimated that after a six-month production break only 75 percent of the trained personnel are available and they have lost 33 percent of their learning. The learning retained in personnel is

$$\begin{array}{ccccc} \text{Weight} & & \text{Personnel} & & \text{Learning} & & \\ .20 & \times & .75 & \times & .67 & = & .10. \end{array} \qquad \text{(C.1)}$$

Personnel learning loss is found by subtracting retained learning from the weight: $.20 - .10 = .10$.

For continuity of production, it is estimated that all learning is lost because workstations are dismantled during the break. Sixty percent of the tooling is said to be available, and 90 percent of the methods sheets are estimated to be usable and available. Total lost learning, therefore, is 50 percent:

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[2]Anderlohr, George, "What Production Breaks Cost," *Industrial Engineering*, September 1960, pp. 34–36.

Continuity of production:
Retained learning = 0
Lost learning = .20 – 0 = .20
Tooling:
Retained learning = .60 × .20 = .12
Lost learning = .20 – .12 = .08
Methods:
Retained learning = .90 × .20 = .18
Lost learning = .20 – .18 = .02
Total lost learning = .10 + .10 + .20 + .08 + .02 = .50. (C.2)

If the first production article required 1,000 factory hours and the 50th, the final one before the interruption, required only 400 hours, total learning would be 600 hours. Half of that, or 300 hours, would be lost when production restarted. It is assumed that the slope of the learning curve does not change. If the original curve had an 85-percent slope, a 50-percent loss of learning means that new production will begin at a quantity of 4.6 on the curve.

Using the ASD model, a six-month interruption gives a learning loss of 40 percent of the units produced, i.e., in the example above, 20 units. Production restart would begin at unit 30. The Douglas model would give a comparable value. Thus, for the assumptions above, the Anderlohr model estimates greater loss of learning. An estimator familiar with conditions at a particular company would probably use different weights and arrive at a different conclusion.

The Aerospace Corporation's GAPMODEL

Researchers at The Aerospace Corporation used the same approach in developing GAPMODEL, a computerized production-break model for estimating production hours.[3] Like the Anderlohr model, it has five learning elements: production labor, production supervision, planning, methods and support, and tooling. The structure is more detailed, however. The five learning elements are subdivided, and the estimator assigns a weight to each. The default weights (percent-

[3]Neiss, J. A., and R. M Selter, *GAPMODEL: A Computerized Production Break Model*, El Segundo, Calif.: The Aerospace Corporation, Report TOR-0089(4464-03)-1, December 1, 1988.

ages) are shown in Table C.1. All default values in the model are said to have been derived from "historical data from various aircraft, space, and missile programs."

The estimator must then estimate the *loss of availability* or use a default value calculated by the model as a function of the length of the production break. The final factor is *knowledge retention*, which for production labor and supervision is calculated by the model as a function of break duration. Weight, loss of availability, and knowledge retention are multiplied together to obtain the *retained ability* for each element. For tooling, for example, the procedure would be as follows:

Weight		Availability		Knowledge Retention		Retained Ability	
8	×	90%	×	100%	=	7.2.	(C.3)

Total retained ability is a percentage that is applied to the number of units in the original production lot. With 50 units in the original lot, for example, and a retained ability of 40 percent, the production hours for the first unit after the interruption would revert to unit 21 on the learning curve.

Table C.1

GAPMODEL Historical Default Values

Element	Weight	Element	Weight
Production labor	50.00	Planning	
Robotics		Configuration	2.50
Retained		Materials	2.50
Reacquire		Processes	2.50
New hire		Equipment	2.50
Production supervision	15.00	Methods and support	
Retained		Layout	4.25
Reacquire		Commonality	4.25
New hire		Positioning	4.25
Tooling	8.00	Coordination	4.25

To validate the model, GAPMODEL outputs were compared with actual data from interruptions ranging from 3 to 28 months in LRU production in the Minuteman ICBM program. For one set of data cited in the GAPMODEL report the average variance was 7.75 percent, and the greatest variance was 15 percent.

Figures C.2 and C.3 compare GAPMODEL estimates with those obtained from the ASD and Anderlohr models. From Figure C.2 it appears that, when the default values are used and the production gap ranges between 6 and 36 months, all three models give roughly the same results. However, as shown by Figure C.3, outputs vary considerably when the inputs are changed, especially for the Anderlohr model.

Figure C.3 illustrates the range between minimum-loss and maximum-loss cases. In the former, knowledge retention is stipulated to be 100 percent for planning, methods, and tooling. Maximum loss is defined as zero retention for labor and 30 percent retention for the other elements. The Anderlohr model is much more sensitive to that range of inputs than is GAPMODEL because of the difference in assumptions regarding production and supervisory labor. Neiss and

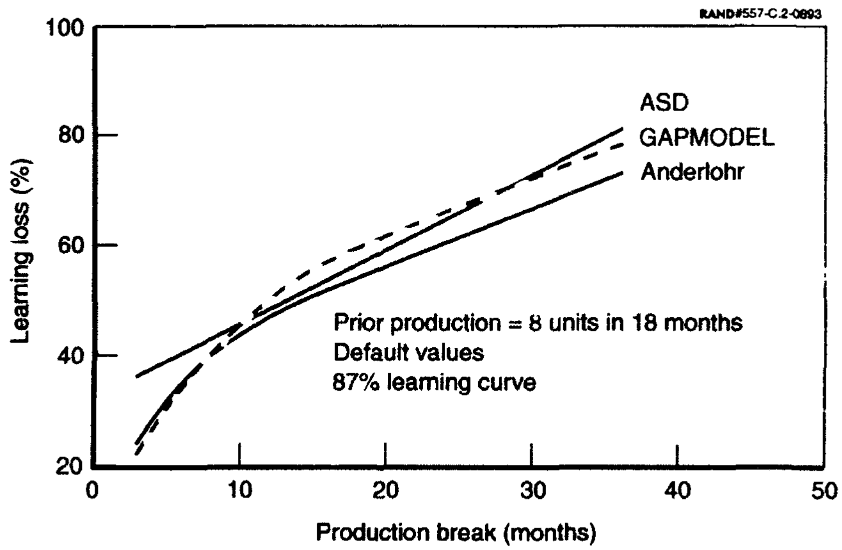

Figure C.2—Comparison of Three Learning-Loss Models

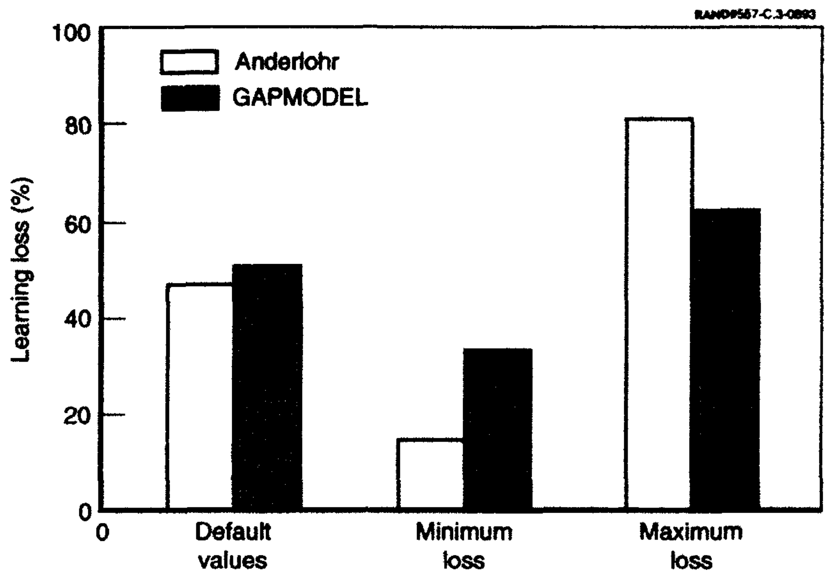

Figure C.3—Minimum and Maximum Losses

Selter do not believe that the learning loss for a 12-month break could be as low as the Anderlohr estimate of 15 percent. Local conditions are the determining factors, *not* the length of the production break.

GILBRIDE MODEL

The Anderlohr model and GAPMODEL agree that the determining factors are personnel, planning, methods, and tooling. Thomas J. Gilbride, an analyst in the Naval Air Systems Command, added to that list and developed a set of tables to be used in assigning values to each of what he called "major impact areas,"[4] i.e., personnel, tooling, etc. The full list is shown in Table C.2, along with the breakdown of each area.

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[4]Gilbride, Thomas J., Unpublished report, Naval Air Systems Command, Official Use Only.

Table C.2

Factors Determining Loss in Gilbride Model

Personnel
Hands-on experience
Qualified but not experienced
New or inexperienced
Tooling
Hard
Soft
Manufacturing methods and operations procedures
No changes or updating
Significant changes or updating
Near complete rewriting and updating
Effort performed during production break
Spare parts for disrupted item
Work similar to that on disrupted item
Minimal similarity to work on disrupted item
Training and supervision
Length of production break
Contract type
Firm fixed price (FFP)
Fixed price incentive (FPI)
Cost plus incentive fee (CPIF)
Cost plus fixed fee (CPFF)

The final area, contract type, is unusual for a production-break model. Gilbride assumes that a change in contract type can affect "management decision-making and the subsequent (proposed) manufacturing man-hour estimate." When the change is from an FFP contract to any other type after a break, Gilbride assigns a negative impact value, which has the effect of reducing the amount of learning lost. Conversely, switching from CPFF to FFP increases the impact value. The effect is minor, however. The drivers in this model are personnel type, manufacturing methods and operations procedures, and effort performed during the production break.

This method requires that both contractual parties agree on the method, tables, and exhibits. They are expected to jointly review the tables provided for each impact area and develop an overall impact value, i.e., a percentage value based on the estimated impact of a given set of conditions. That value is translated into an adjustment value by reference to another table or exhibit. The adjustment value is multiplied by the prior production quantity to obtain the loss of learning, i.e., the number of units of learning lost because of the interruption. For example, with a prior production quantity of 150 and an adjustment value of 0.14, the number of units lost would be 21 ($150 \times 0.14 = 21$). Production would restart at unit 130 on the learning curve.

The adjustment values in the exhibits are related to the number of years of production prior to the production break and to the break time, as shown in Figure C.4. As break time increases, the adjustment value or loss of learning increases. That effect is mitigated by the years of production, however. After eight years of production, a five-year break would have much less of an impact than after one year of production.

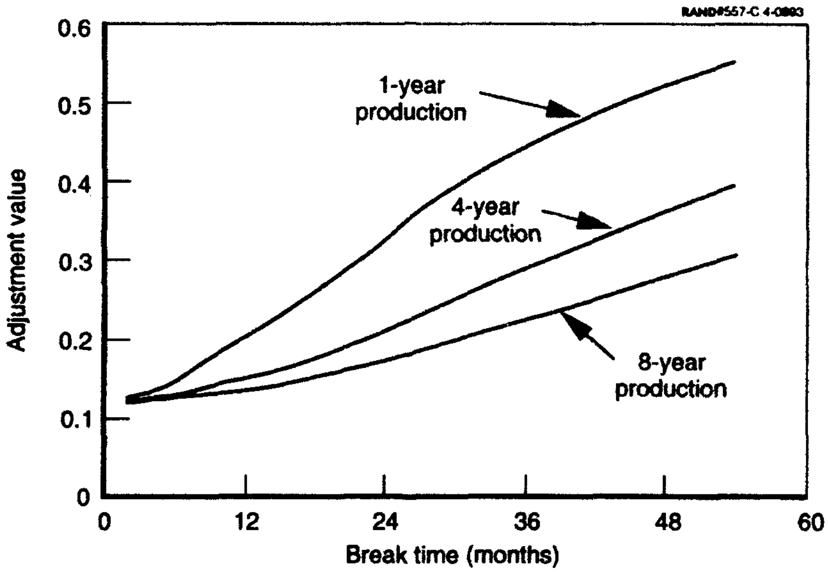

Figure C.4—Gilbride Model: Impact Value = 20

Appendix D

SUMMARY OF RESTART SCHEDULES

SUMMARY OF RESTART SCHEDULES

Table D.1 provides the historical schedule data from which Figure 2.1, Production Restart Schedules (Chapter Two), is derived.

Table D.1

Summary of Restart Schedules

Phase	Programs with Actual Restarts							Proposed Restarts[a]			
	B-1[b]	C-5	U-2[c]	Jetstar[d]	OV-10	UH-2	AGM-65[e]	CH-46[f]	F-117	S-3	B-707[g]
Initial phase											
Project start or contract date	6-70	10-65	12-54	1-57	9-64	?-57	6-68	5-57	11-78	8-69	5-52
First flight	12-74	6-68	8-55	9-57	6-65	7-59		8-62	6-81	1-72	7-54
First prod. delivery	—	12-69		4-61	7-67	12-62	6-72	1-63	6-82	9-73	6-57
Last delivery	2-79	6-73		4-63	4-69	?-65	8-78	2-71	6-90	8-78	5-91
Quantity	4	81	53	61	271	190	25,800	601	59	197	1,010
Restart	B-1B	C-5B	U-2R								
Project start or contract date	10-81	10-82	7-67	—	6-69	7-81	5-80				
First flight	10-84	9-85	3-68	—							
First prod. delivery	6-85	12-85	5-68	5-64	4-70	12-83	8-81				
Last delivery	4-88	3-89	10-68	?-73	3-71	?-89	4-84				
Quantity	100	50	12	101	34	54	4,594				
Contract to 1st delivery—initial (months)	—	50	—	51	34		48	—	43	49	59
Contract to 1st delivery—restart (months)	36	38	10	—	10	29	15	36	29	39	42

Table D.1—continued

Phase	Programs with Actual Restarts							Proposed Restarts[a]			
	B-1[b]	C-5	U-2[c]	Jetstar[d]	OV-10	UH-2	AGM-65[e]	CH-46[f]	F-117	S-3	B-707[g]
Last–first gap (months)	76	150		13	12	-200	36	—	—	—	—
			TR-1								
Second restart											
Project start or contract date			4-79	—	12-71						
First flight			5-81	8-76							
First prod. delivery			5-81	12-76	1-73						
Last delivery			6-89	?-80	11-73						
Quantity			37	40	32						
Contract to 1st delivery—restart (months)			25	—	14						
Last–first gap (months)			149	-40	22						
Third restart											
Project start or contract date					3-75						
First flight											
First prod. delivery					9-76						
Last delivery					2-77						
Quantity					16						

Table D.1—continued

Phase	Programs with Actual Restarts							Proposed Restarts[a]			
	B-1[b]	C-5	U-2[c]	Jetstar[d]	OV-10	UH-2	AGM-65[e]	CH-46[f]	F-117	S-3	B-707[g]
Contract to 1st delivery—restart (months)					18						
Last-first gap (months)					34						

[a]Time shown for restart contract-to-first-delivery is the quotation provided by the supplier in the proposal for restart. While the proposals were made at various times from the late 1980s to the early 1990s, we assume that the exact timing of the proposed restart would not have a large effect on the elapsed time between events.

[b]Program canceled before production phase. "Last delivery" was fourth test aircraft.

[c]First restart is the U-2R program, a modification of the original U-2A. The second restart is TR-1 program, a design similar to the U-2R.

[d]Initial development was a commercial venture, which makes the initial-phase time from project start to first delivery somewhat different from that of typical military development programs. First restart represented a pause in production to align supply with orders. There was a *distinct new contract to initiate restart. Second restart represented a model change from Jetstar I to Jetstar II.*

[e]On the restart (RMS buy) of the AGM-65, Maverick is assumed to have started in May 1980, when the contractor issued purchase orders for long-lead material.

[f]The CH-46 was initially developed as a corporate-sponsored program, with later procurement by military agencies. Therefore, initial "time to develop" is not comparable with that of conventional programs.

[g]The program-start and first-flight dates are for the company-sponsored model 367-80 prototype. First delivery was the military KC-135, with subsequent production of the commercial 707. Although the designs differed in detail, they are considered members of one continuous program. The dates for the B-707 program are project start, 9-55; first flight, 12-57; and first delivery, 8-58.

Appendix E

RESTART LEARNING-CURVE ANALYSES

As mentioned in the main text, the data collected for this project contain 49 cases in which a restart can be compared with an original program. These 49 cases represent 10 programs and 11 contractors. They permit 21 multiple-lot comparisons of recurring costs, 18 multiple-lot comparisons using the sum of nonrecurring and recurring costs, and 10 cases of single-point restarts versus the original program. The approach used in this appendix compares fitted learning curves for the original programs with either fitted learning curves or single points for the restart programs.

Material costs have not been addressed in this study because few data regarding materials were available and most of the program costs are accounted for by the labor elements. The material costs referred to here exclude engines and avionics. They include raw materials, purchased parts, and high-value items necessary to make an airframe and its subsystems (hydraulics, electrical, environmental control, etc.). The material element accounts for slightly less than 20 percent of the total cost; the labor categories account for the remaining 80 percent. (See Table 2.2.)

It is important to keep in mind that this 80–20 split represents the government's view of the airframe portion of the program. Today, there is considerable talk about programs involving 60 to 80 percent, or more, purchased material. Such statements are made from the prime contractor's point of view and reflect significant amounts of teaming plus addition of extensive avionics responsibility to the contractor. To see how this works, take half of the labor in the above example and give it to a "principal subcontractor." Now the prime contractor's labor drops from 80 percent of the total cost to 40 percent, and the prime is in a position of managing 60 percent of the program through its subcontracting organization rather than the original 20 percent. If $2.5 billion of avionics responsibility is added to the prime contract (again, see Table 2.2), then both the material element and the total program cost are increased by this amount, and the prime contractor has subcontract management responsibility for approximately 80 percent of the total program cost and direct labor responsibility for only 20 percent. The government is buying the same product in all these cases, but the prime contractor's responsibility is significantly different in both scope and distribution of type of effort. This change has significant implications for the importance of the subcontracting organization when programs with teaming arrangements and prime-contractor avionics responsibility are shut down.

When learning-curve data for a program with a production break and restart are plotted with the restart data in sequence, there is a jump in the curve at the restart point. This jump represents loss of learning. Following the restart point, unit costs decrease rapidly compared with the rate of decay for the original program. A typical set of results is shown in Figure E.1. Replotting data from the quality curve in Figure E.1 as two separate sets of data and fitting regressions results in two learning curves as shown in Figure E.2. The restart learning curve starts at a lower first-unit value and has a shallower slope than the curve for the original program. This relationship between the two curves resulted for 37 of the 39 cases examined in this study. Only the B-1 failed to fit this pattern, and full-production capability had not been established in the original program. Furthermore, for the 10 cases in which only a single restart point was available, nine of the restart points are below the original program learning curve and the remaining point is on the line. From this evidence, it can be concluded with a high degree of confidence that restarting an aircraft production line will be characterized by restart

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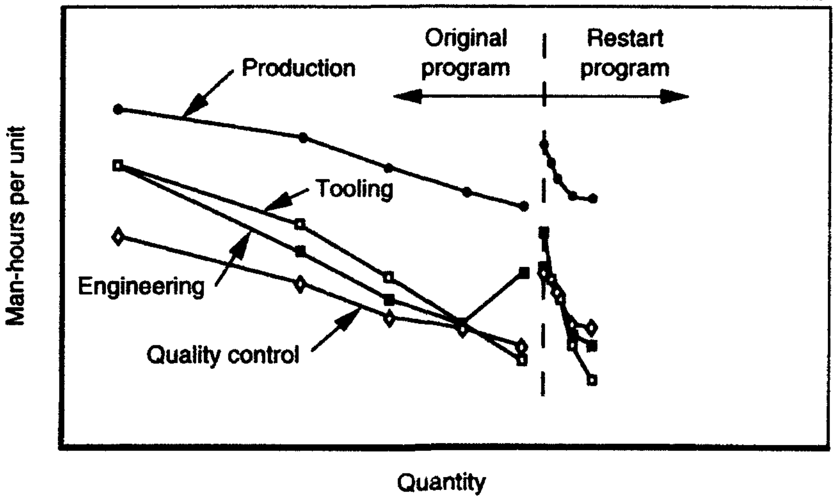

Figure E.1—Original and Restart Man-Hours per Unit Versus Quantity, Plotted Sequentially

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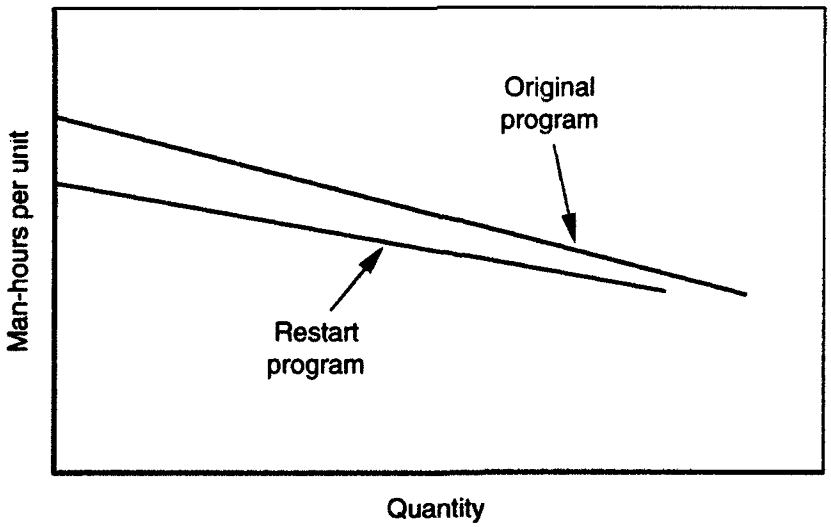

Figure E.2—Man-Hours per Unit Versus Quantity, Plotted Separately for Original and Restart Productions

learning curves that begin below the original curve and have shallower slopes.[1]

Several measures can be used to compare and analyze pairs of learning curves that exhibit the characteristics of the restart curves shown in Figure E.2, including:

- The ratio of the restart first-unit costs to the original first-unit costs: RT_1/OT_1
- The slopes of the original and restart curves: OS and RS
- The quantity at which the unit cost on the original curve is equal to the first-unit cost of the restart curve: $Q(OT_q = RT_1)$
- The ratio of the cost of the original program quantity as indicated by the original learning curve to the cost of the same quantity produced on the restart learning curve: $(R\$/O\$)$, OQ
- The ratio of the quantity of units that can be produced on the restart program for the same cost as the original program to the original quantity: (RQ/OQ), $O\$$.

The following sections present specific results for the four functional labor categories.

ENGINEERING

Recurring engineering data were obtained for the C-5 and S-3 programs, the latter from both Lockheed and LTV. Total (nonrecurring plus recurring) lot-by-lot data were obtained for the S-3 (both Lockheed and LTV) and the OV-10 programs. The OV-10 had three production gaps, two with multiple lots following the break and one with only a single lot following the break. In cases with more than one production gap, the original program was used as the reference point for all restarts. These data permitted seven learning-curve comparisons between the original programs and restarts, four using

[1]Such pairs of learning curves will eventually cross if projected to sufficiently high quantities, and a few of the best-fit unit-cost curves in this study did cross within the range of the data. However, learning curves are to some extent managed. It is unlikely that a contractor would allow a restart curve to remain above the original curve.

total costs and three using recurring costs. In addition, the CH-46, F-117, and OV-10 (third restart) provide single-point restart comparisons, and all restart points are below the original learning curve. The learning-curve results are summarized in Table E.1. As expected, the measures for total costs are different from those for recurring costs, but because of the small sample sizes not all the differences are statistically significant.

TOOLING

Tooling data are available for the same programs as for engineering. B-1 tooling data are also available, but the B-1A program did not achieve full-production capability before it was canceled. Consequently, the restart (B-1B) tooling is significantly larger than the original (B-1A) tooling, and these data are not included in the learning-curve analyses (Table E.2).

PRODUCTION

Production labor data are available for the same programs as for engineering and tooling, and total production data are available for the F-117 program. Recurring production data are available for the AGM-65A/B (fabrication and assembly), the Lockheed Jetstar (assembly labor only; two gaps, the second between models I and II),

Table E.1

Summary of Engineering Restart Learning-Curve Analyses

	Observations						
Measure	Total Hours				Recurring Hours		
RT_1/OT_1 (%)	7	2	2	1	33	27	6
OS (%)	44	47	54	54	59	64	61
RS (%)	65	78	72	83	65	77	94
$Q(OT_q = RT_1)$(units)	10	34	71	175	4	7	51
$(R\$/O\$)$, OQ (%)	29	21	10	10	48	70	62
(RQ/OQ), $O\$$ (units)	22	11	76	23	5.3	18	17

Table E.2

Summary of Tooling Restart Learning-Curve Analyses

Measure		Observations							
		Total Hours					Recurring Hours		
RT_1/OT_1	(%)	32	10	2	1	309	55	48	18
OS	(%)	55	51	62	62	62	82	66	58
RS	(%)	62	66	90	92	76	83	72	67
$Q(OT_q = RT_1)$	(units)	4	11	260	446	0	8	4	9
$(R\$/O\$), OQ$	(%)	52	28	19	15	371	58	70	32
$(RQ/OQ), O\$$	(units)	6.2	19	7.2	8.5	0.2	2.1	1.9	12

the U-2R to TR-1 gap, the LAMPS Mark I, and the CH-46.[2] A single-point comparison is available for the OV-10 (third restart), which is below the original learning curve. Learning-curve results are summarized in Table E.3.

QUALITY ASSURANCE

Quality-assurance data are available for the same programs as for engineering and tooling, and test labor hours are available for the AGM-65A/B. Single-point restart comparisons for the F-117 and OV-10 (third restart) show the restart points below the original learning curves, whereas the restart point for the CH-46 is on the original curve. Learning-curve results are summarized in Table E.4.

[2]B-1 data are available for production labor but have not been included in the analysis because full-production capability was not established and the original and restart learning curves do not fit the pattern exhibited by all other observations in the study.

Table E.3

Summary of Production Restart Learning-Curve Analyses

Measure		Observations									
		Total Hours									
RT_1/OT_1	(%)	58	37	29	28	22	79				
OS	(%)	85	75	79	69	79	93				
RS	(%)	89	83	90	83	96	77				
$Q(OT_q = RT_1)$	(units)	11	12	36	10	83	9				
$(R\$/O\$)$, OQ	(%)	71	64	67	80	76	64				
(RQ/OQ), $O\$$	(units)	1.5	1.8	1.6	1.4	1.3	1.8				
Measure		Recurring Hours									
RT_1/OT_1	(%)	82	76	61	55	54	53	40	38	35	29
OS	(%)	77	92	87	79	80	77	75	74	81	74
RS	(%)	85	93	91	87	83	84	85	86	94	89
$Q(OT_q = RT_1)$	(units)	2	10	11	5	7	5	9	9	31	17
$(R\$/O\$)$, OQ	(%)	101	88	109	116	68	88	69	65	85	59
(RQ/OQ), $O\$$	(units)	1.0	1.2	0.9	0.8	1.7	1.2	1.6	1.7	1.2	1.9

Table E.4

Summary of Quality Restart Learning-Curve Analyses

Measure	Observations							
	Total Hours				Recurring Hours			
RT_1/OT_1 (%)	47	30	26	17	74	51	48	35
OS (%)	72	68	74	74	83	74	75	73
RS (%)	77	84	84	92	85	80	75	83
$Q(OT_q = RT_1)$ (units)	5	9	23	64	3	5	6	10
$(R\$/O\$)$, OQ (%)	67	97	55	64	103	75	110	70
(RQ/OQ), $O\$$ (units)	1.9	1.0	2.2	1.7	1.0	1.5	0.9	1.6

Appendix F

REGRESSION ANALYSES

This appendix presents the results of regression analyses performed to determine which characteristics of restart programs are most correlated with restart costs. Appendix C describes several models that were developed in the past to estimate the costs of restarting production activities after an interruption in production or a shutdown. All of those studies consider only recurring production labor, and most of them relate the restart first-unit cost to the length of the production break and use the same slope as the original program for projecting restart costs. The study related here looks at all four major labor categories—engineering, tooling, production, and quality assurance—and addresses both nonrecurring and recurring costs.

As shown in Table 2.3 of of this report, there are only three programs for which separate nonrecurring cost data are available. These data are inadequate by themselves for performing regression analyses for nonrecurring costs. Consequently, this appendix focuses on the data available from the learning-curve analyses.

The available variables include the original-program first-unit cost and slope (OT_1 and OS, respectively), the quantity produced on the original program (OQ), the length of the production gap (L), and the restart-program first-unit cost and slope (RT_1 and RS, respectively). Of course, RT_1 and RS are the dependent variables, and the others are potential explanatory variables.

Multivariate, ordinary least-squares regressions were run to relate restart first-unit cost and slope to the potential explanatory variables. Regressions were determined for four subsets of the 37 available cases. The first subset includes recurring-cost cases for the aircraft programs (C-5 and S-3 data for all four labor categories, plus the Jetstar, U-2, LAMPS, and CH-46 data for production labor). The AGM-65 was omitted because it is a missile. The total number of observations in this case is 17. The second subset comprises all recurring-cost cases, including the AGM-65, bringing the total number of observations to 20 (the AGM-65 has fabrication, assembly, and test data). The third subset includes only the *total-cost* (nonrecurring plus recurring) cases. This subset includes the S-3 and OV-10 for all four labor categories, plus production labor for the F-117. This subset also has 17 observations. The final subset consists of all observations (37).

The best equations for the restart first-unit cost are summarized in Table F.1. The coefficients of determination, F values, and t values are all quite good, but the standard errors of the estimate are disturbingly high. As the equations show, restart T_1 is highly correlated with original T_1 and slope. The total and combined regressions include the length of the production gap, but the recurring equations do not. This difference would indicate that the length of the gap has a significant effect on the nonrecurring costs of a restart but not on the recurring costs. In no case does the original-program quantity make a significant contribution to any of these equations.

A few additional comments should be made on the length of the production gap. Regressions using the gap length without taking the natural logarithm are also significant for the total and combined samples (and not for the recurring samples). The statistics for the combined equation using $\ln(L)$ are slightly superior to the statistics for the nonlog equation, and the opposite is true for the total equations. The $\ln(L)$ versions were selected because their coefficients yield more reasonable results for the effect of gap length. The coefficients in Table F.1 indicate that a 10-year gap would result in a restart value that is 3.1 times higher than for no gap using the total equation and 2.3 times higher for the combined equation. For the nonlog equations, the corresponding multipliers are 6.6 and 2.1. We concluded that the 6.6 factor was too high in comparison with the others, and, thus, the non-log versions were rejected.

The best restart slope equations for the four subsets are summarized in Table F.2. The coefficients of determination are not as good as for

Table F.1

Equations for Restart First-Unit Cost

Recurring costs, excluding AGM - 65 :

$$\ln(RT_1) = -1.1412 + 1.1225 * \ln(OT_1) + 4.1158 * \ln(OS)$$
$$(t = 11.36) \qquad (t = 3.87)$$

coefficient of determination = 0.903
standard error of estimate = 0.43
F = 65.3

Recurring costs, including AGM - 65 :

$$\ln(RT_1) = -0.6124 + 1.0280 * \ln(OT_1) + 3.8226 * \ln(OS),$$
$$(t = 23.15) \qquad (t = 3.85)$$

coefficient of determination = 0.978
standard error of estimate = 0.42
F = 379.1

Total (nonrecurring plus recurring) costs:

$$\ln(RT_1) = -3.1279 + 1.0704 * \ln(OT_1) + 5.9386 * \ln(OS) + 0.7316 * \ln(L),$$
$$(t = 5.98) \qquad (t = 5.39) \qquad (t = 3.12)$$

coefficient of determination = 0.885
standard error of estimate = 0.74
F = 33.4

Combined (total and recurring)costs:

$$\ln(RT_1) = -1.8614 + 1.0097 * \ln(OT_1) + 5.2664 * \ln(OS) + 0.5247 * \ln(L),$$
$$(t = 16.72) \qquad (t = 7.22) \qquad (t = 4.30)$$

coefficient of determination = 0.932
standard error of estimate = 0.64
F = 150.4

Table F.2

Equations for Restart Slope

Recurring costs, excluding AGM-65:

$$\ln(RS) = 0.02669 + 1.1638 * \ln(OS) - 0.16129 * \ln(RT_1/OT_1)$$
$$(t=9.28) \qquad (t=-6.65)$$

coefficient of determination = 0.860
standard error of estimate = 0.041
F = 43.1

Recurring costs, including AGM-65:

$$\ln(RS) = 0.003015 + 1.0955 * \ln(OS) - 0.15895 * \ln(RT_1/OT_1)$$
$$(t=10.41) \qquad (t=7.00)$$

coefficient of determination = 0.865
standard error of estimate = 0.39
F = 54.7

Total (nonrecurring plus recurring) costs:

$$\ln(RS) = -0.01141 + 0.7304 * \ln(OS) - 0.06276 * \ln(RT_1/OT_1)$$
$$(t=8.62) \qquad (t=-5.12)$$

coefficient of determination = 0.843
standard error of estimate = 0.050
F = 37.5

Combined (total and recurring) costs:

$$\ln(RS) = -0.01123 + 0.8057 * \ln(OS) - 0.07800 * \ln(RT_1/OT_1)$$
$$(t=11.50) \qquad (t=-7.52)$$

coefficient of determination = 0.798
standard error of estimate = 0.050
F = 67.2

the restart T_1 regressions, but they are not bad; the other statistics are all good. Again, the dependent-variable restart slope is most highly correlated with the original-program slope. In all cases the next-most-significant variable is the ratio of the restart and original first-unit costs.[1] Neither the length of the production gap nor the original program quantity yields a significant improvement to these equations.

With the exception of the standard errors of the estimate for the RT_1 regressions, which are too high, the statistics are good for all equations. However, the total equations are based on only three programs (the S-3, both Lockheed and LTV; the OV-10, two restarts; and the F-117, a single observation for production labor), and two of those are proposed restarts. Thus, if these equations are used to estimate restart-program costs, the combined equation should be the preferred equation, and the total equation should be used as a secondary test of reasonableness.

For the restart-slope equations, adding the natural log of the original production quantity to both recurring equations above results in slight improvements in the coefficients of determination and standard errors of the estimate and a slight degradation in the F values. The Student t values for the additional terms show the variable to be insignificant at the 20-percent level.

Table F.3 presents the results of this study and those of previous studies, for comparison.

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[1]Regressions were run with both restart T_1 and original T_1 as separate variables, and their coefficients were very nearly equal in magnitude. Thus, the ratio was attempted as an explanatory variable and the statistical properties of the equations were improved.

Table F.3

Past and Current Restart-Study Results for Comparison

Measure	Past Studies	Current Study
Experience considered	Recurring production labor	Nonrecurring and recurring; engineering, tooling, quality assurance, and production labor
Magnitude of restart first-unit cost	Less than original	Less than original
Restart slope	Same as original	Shallower than original
Restart first-unit cost drivers	Length of gap	Original first-unit cost and slope; gap length more related to nonrecurring
Restart-slope drivers	N/A	Original slope and ratio of first-unit costs

Appendix G

DETAILED SCREENING OF SELECTED SYSTEMS

Details of the screening process discussed in Chapter Four are presented in this appendix. The following tables list every system that survived the first screening step—that is, every system that is, or has been, in production and for which procurement appropriations are not programmed beyond 1995. The time span of procurement appropriations is shown in bar charts on the right-hand side of the tables.[1] Each entry is labeled with a "Y" or "N," which represents a *yes* or *no*, respectively. In the "Future need plausible?" columns, some entries are left blank, because only one yes response is needed to justify processing to subsequent steps of the screening analysis.

[1]These data are drawn from SARs dated December 1991. Funding projections are under constant review, so the data shown might not be consistent with the most recent service position. However, such discrepancies are likely to affect few, if any, of the overall conclusions offered here.

Table G.1

Detailed Screening of Army Systems

System	Future Need Plausible?: Attrition or consumption	Future Need Plausible?: Increase in force size	Produce close substitute	Draw from storage	Wait for next system	Source?: Currently operational	Source?: Restart candidate
AH-64 Apache	Y		N	N	N	Y	Y
ATACMS	Y		N	Y	N	Y	Y
Bradley FVS	Y		N	N	N	Y	Y
CH-47/MH-47	Y	Y	N	N	N	Y	Y
FHTV (PLS)	N	N	N	Y	N	Y	N
Hellfire missile	Y		N	N	Y	Y	N
M1 tank	Y		N	Y	Y	Y	N
MSE comm. system	N	N	N	N	Y	Y	N
OH-58D (AHIP)	Y	Y	N	N	N?	Y	Y?
Stinger-RMP missile	Y		N	Y	Y	Y	Y
TOW-2 missile	Y		N	Y	Y	Y	N

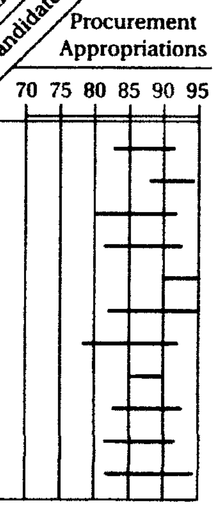

Table G.2

Detailed Screening of Navy Systems

System	Future Need Plausible?		Source?				
	Attrition or consumption	Increase in force size	Produce close substitute	Draw from storage	Wait for next system	Currently operational	Restart candidate
A-6E	Y	Y	N	N	N	Y	Y
AGM-88 HARM	Y		N	Y	N	Y	Y
AIM-7M Sparrow	Y		Y	Y	Y	Y	N
RIM-7M Sea Sparrow	Y		N	Y	N	Y	Y
AIM-9M Sidewinder	Y		N	Y	N	Y	Y
AIM-54C Phoenix	Y		Y	Y	N	Y	N
AN/BSY-1/2	N	Y	N	N	N	Y	Y
AN/SQQ-89	N	Y	N	N	N	Y	Y
AOE-6 class	N	Y	N	N	N	Y	Y
A/R/UGM-84 Harpoon	Y		N	Y	N	Y	Y
AV-8B Harrier II	Y	Y	N	N	N	Y	Y
CG-47 Cruiser	N	Y	Y	N	Y	Y	N
C/MH-53E	Y	Y	N	N	N	Y	Y
E-2C	N	Y	N	Y	N	Y	Y
E-6A	N		Y	N	N	Y	N
F-14D	Y	Y	Y	Y	N	Y	N
FFG-7 class	N	Y	N	N	N	Y	Y
LCAC-1 class	Y	Y	N	Y	N	Y	N
LHD-1 class	N	Y	N	N	N	Y	Y
LSD-41 class	N	Y	N	N	N	Y	Y
MCM-1 class	Y	Y	N	N	N	Y	Y
MHC-51 class	Y	Y	N	N	N	Y	Y
R/UGM-109 Tomahawk	Y	Y	N	Y	N	Y	Y
S-3A/B	Y	Y	N	N	N	Y	Y
T-AO-187 class	N	Y	Y	Y	N	Y	N
UHF Follow-on	Y		Y	N	Y	Y	N

Procurement Appropriations

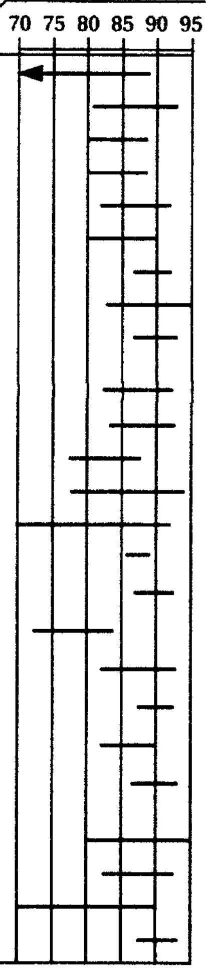

Table G.3

Detailed Screening of Air Force Systems

	Future Need Plausible?					Source?		
System	Attrition or consumption	Increase in force size	Produce close substitute	Draw from storage	Wait for next system	Currently operational	Restart candidate	Procurement Appropriations 70 75 80 85 90 95
A-10	Y	Y	N	N	N	Y	Y	
AGM-65 IIR Maverick	Y		N	Y	N	Y	Y	
AGM-88 HARM	Y		N	Y	N	Y	Y	
AGM-129 adv. cruise missile	Y		N	N	N	Y	Y	
AIM-7M Sparrow	Y		Y	Y	Y	Y	N	
AIM-9M Sidewinder	Y		Y	Y	Y	Y	N	
ALCM	Y		N	Y	Y	Y	N	
B-1B	Y	Y	N	N	N	Y	Y	
B-2	N	Y	N	N	N	Y	Y	
C-5B	N	Y	N	N	?	Y	?	
CSRL	N		N	Y	N	Y	N	
DMSP	N		N	N	Y	Y	N	
DSCS-III	N		N	N	Y	Y	N	
E-3A AWACS	N	N	N	N	Y	Y	N	
F-15	Y		N	Y	Y	Y	N	
F-16	Y		N	Y	?	Y	?	
F-117	Y	Y	N	N	N	Y	Y	
GLCM	Y		N	Y	N	Y	N	
IUS	Y		N	N	N	Y	Y	
KC-10A	N	Y	N	N	Y	Y	N	
LANTIRN	Y	Y	N	N	N	Y	Y	
LGM-118A Peacekeeper	Y		N	Y	Y	Y	N